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SOIL SCIENCE

Contents for October, 1921

# NUTRIENT REQUIREMENTS OF CLOVER AND WHEAT IN SOLUTION CULTURES[1]

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The nutrient requirements of the clover plant and the ratio of phosphate, nitrate and potassium best suited for their growth was studied in aqueous culture solutions, containing calcium acid phosphate ($CaH_4(PO_4)_2.H_2O$), sodium nitrate ($NaNO_3$), and potassium sulfate ($K_2SO_4$), used singly and in combinations. In this work the solutions were prepared according to the triangular scheme (2), in a similar manner as were the ratio studies made in this laboratory with wheat, reported in a former publication (1).

The details of the methods of experimentation were similar to those described in the earlier work. The red clover seeds (*Trifolium pratense*) were germinated in sand, and put in the culture solutions when about ½ inch high. Ten plants were grown in each culture for 35 days, the container holding 250 cc. of the solutions. The solutions were changed from time to time, and an analysis made to determine the amount of phosphate, nitrate and potash absorbed. The concentration of the salts in the solution was 80 parts per million of $P_2O_5$,$NH_3$ and $K_2O$, there being 66 solutions. Some contained each of the salts singly, some had combinations of two salts and others combinations of three, the ratio of the constituents varying in 10 per cent differences. The triangular plan used in the experiment is familiar, and is readily understood when reference is made to figure 1, or to the paper cited.

In figure 1 the points in the triangle which are numbered represent the composition of the culture solutions. No. 1 represents a solution containing only calcium acid phosphate, no. 56 only potassium sulfate and no. 66 only sodium nitrate. The line of cultures 1 to 56 are mixtures of phosphate and potash, the line no. 56 to 66 mixtures of potash and nitrate, and the line no. 1 to 66 mixtures of phosphate and nitrate. The points in the interior represent solutions containing all three constituents; those near the phosphate end are high in that particular element, likewise those in the potash or nitrogen end are high in the respective constituents mentioned. By reference to the earlier work one can easily understand the composition of the solution from its position in the triangle.

In the studies made with young wheat plants, with the use of the complete triangle set of 66 solutions, it was shown that the better growth occurred

[1] Contribution from the United States Laboratories of Soil-Fertility Investigations.

when all three nutrient elements, phosphate, nitrate and potash, were present in the solution, and the best growth in the mixtures which contained between 10 and 30 per cent of phosphate, between 30 and 60 per cent of nitrate and between 30 and 60 per cent of potash. The growth in the solution containing all three elements was much greater than in solutions containing two elements. The absorption in the solutions was also very striking, the greatest absorption occurring where the greatest growth was obtained. The ratio of the materials absorbed by the wheat and its relation to growth, is interesting in connection with the present studies with clover, and this will be discussed later more in detail.

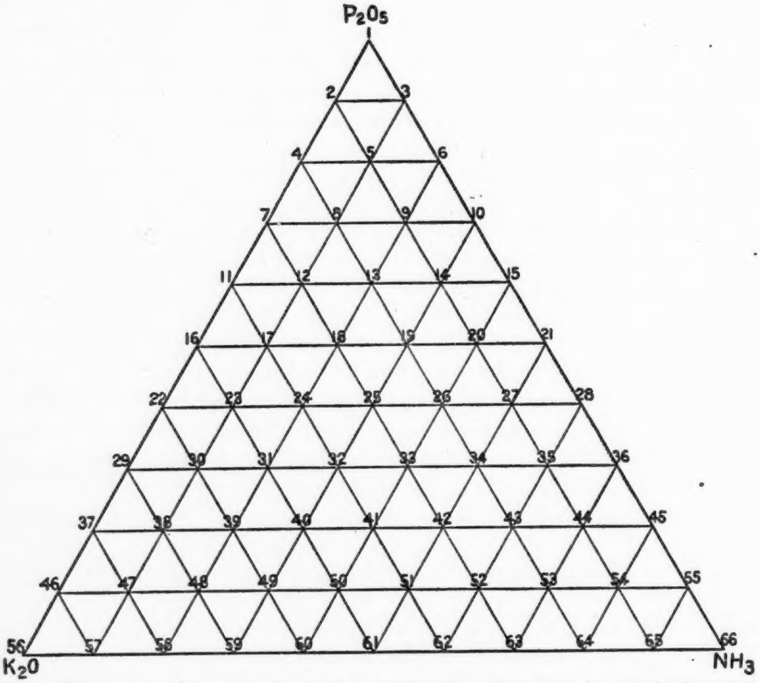


FIG. 1. TRIANGULAR DIAGRAM WITH THE POINTS NUMBERED REPRESENTING THE 66 CULTURE SOLUTIONS

## FERTILIZER RATIO AND CLOVER GROWTH

The green weights of the clover plants, which were grown in the 66 solutions from February 25 to March 27, 1918, are given in the chart in figure 2. The complete triangle set as grown in the greenhouse is shown in plate 1, figure 1. The concentration of the solutions was 80 parts per million of $P_2O_5$, $NH_3$ and $K_2O$. The solutions were changed every 5 days, seven changes being made during the experiment, and an analysis made to determine the amount and

ratio of phosphate, nitrate and potash absorbed. It is observed that the largest growth occurs in those solutions in the interior of the triangle, lying somewhat below the center of the figure, a result very similar to that secured with wheat. That is, the growth of both clover and wheat is best in those solutions containing approximately an equal ratio of nitrogen and potash with a relatively smaller proportion of phosphate. On closer examination of the data here given for clover and those for wheat in figure 3, page 10, of the article cited (1), it is seen, however, that the cultures producing the

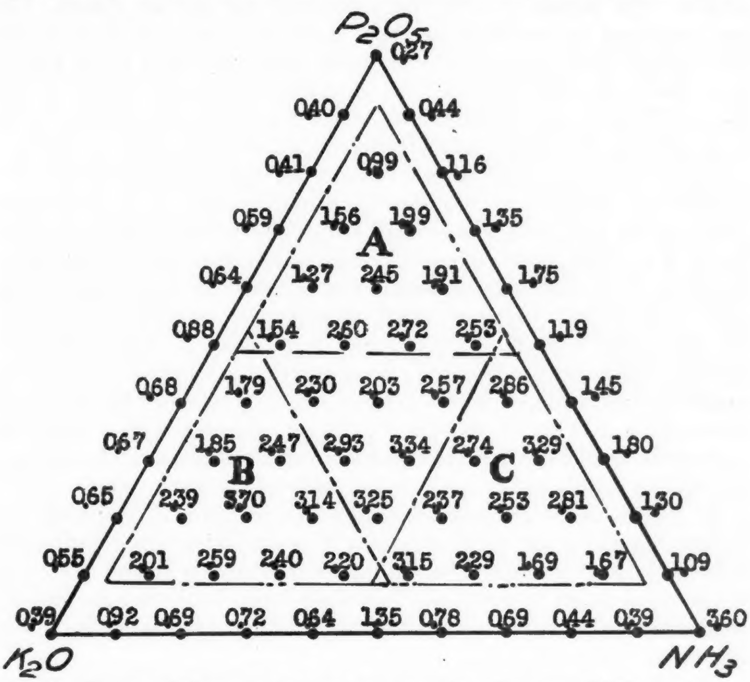


FIG. 2. GREEN WEIGHT OF CLOVER IN GRAMS GROWN IN THE 66 SOLUTIONS

**Sub-triangle *A* contains the solutions which have the three salts, but containing principally phosphate; sub-triangle *B* those containing principally potash, and sub-triangle *C* those containing principally nitrogen.**

maximum clover growth contained a slightly higher proportion of potash and a slightly lower proportion of nitrogen than the cultures which produced the maximum growth of wheat.

The relation of the ratio of the three nutrients absorbed from the solution by clover and by wheat also is of interest. The data show that the clover absorbs a slightly higher ratio of potash than does wheat, the difference being naturally more marked in those solutions containing a higher proportion of potash and nitrogen than phosphate.

The solution cultures as grouped in figure 2, bring together those containing three salts, and having 50 per cent or more of a single constituent. Sub-triangle *A* contains the solution cultures having a high proportion of phosphate; sub-triangle *B* those having a high proportion of potash and sub-triangle *C* those having a high proportion of nitrogen. The ten cultures of sub-triangles *A*, *B* and *C* produced a total growth respectively of 15.5 gm., 25.4 gm. and 24.5 gm. The larger growth occurred in the high potash and the high nitrogen solutions, the growth in the high potash being slightly greater. The culture (no. 39) which produced the greatest growth, 3.70 gm., contained the nutrients $P_2O_5$,$NH_3$ and $K_2O$ in the ratio of 20–20–60. The solution which produced the maximum growth of wheat in the experiment previously cited contained the phosphate, nitrate and potash in the ratio of 20–40–40, the composition of which is higher in nitrogen and lower in potash than the solution which produced the maximum growth of clover.

In plate 1, figure 2 are shown four cultures, one representing each of the sub-triangles just discussed and one from the interior triangle. *A* is a high-phosphate culture and contains phosphate, nitrate and potash in the ratio of 60–20–20; *B* is a high-potash culture and contains the constituents in the ratio of 20–20–60; *C* is a high-nitrogen culture and contains the constituents in the ratio of 20–60–20; *D* has nearly equal proportions of the three constituents, the ratio being 30–40–30. It is seen here that culture *B*, plate 1, figure 2, the high-potash solution, has made a larger growth than the others. The green weights of these cultures, as seen in figure 2, namely solutions 13, 39, 43 and 33, was for *A*, 2.45 gm.; *B*, 3.70 gm.; *C*, 2.53 gm.; and *D*, 3.34 gm. These are representative solutions from each sub-group of the triangle, and it is seen that the solution slightly higher in potash has produced the best growth.

An analysis of the green-weight data shown in figure 2, comparing the cultures containing two constituents with those containing three constituents, is interesting. It is readily observed that in each case the growth where any two constituents are present is less than where three constituents are present, regardless of whether the missing fertilizer constituent is phosphate, nitrate or potash.

Considering first the group of cultures having no phosphate, and 10 per cent phosphate, it is seen that the cultures having no phosphate, that is those along the line 56 to 66 (fig. 1), are much smaller than those having 10 per cent phosphate, as shown in the line 46 to 55. The average green weight of the eleven cultures from the no-phosphate line is 0.641 gm., and that of the cultures from the group of solutions containing 10 per cent of $P_2O_5$ in its composition is 1.962 gm. There is a decrease of 67 per cent in those cultures where the $P_2O_5$ was absent from the solution.

In making a similar comparison from the point of view of the absence of nitrate from a solution, the relation between the line of cultures 1 to 56 and 3 to 57 (fig. 1 and 2) should be studied. The average green weight in the no-nitrate solutions, the group of 11 cultures 1 to 56, is 0.536 gm. against

1.474 gm. as the average growth for the group of 10 cultures having 10 per cent of nitrate in their composition. It is here seen that there is a reduction in growth of 64 per cent when the nitrate is absent.

When a similar comparison is made to show the effect of the absence of potash, it is seen that there is not so marked a reduction as when phosphate or nitrate was left out of the solution. The average growth of the line of 11 cultures having no potash, 1 to 66, is 1.105 gm., as compared with 1.882 gm. for the line of cultures, 2 to 65, having 10 per cent of potash. There is a reduction here of only 40 per cent.

From this comparison one might conclude that potash was less important in the metabolism of the clover plant than is phosphate or nitrate. But such is shown not to be the case when a study is made of the complete set of cultures. Clover does not function properly in a solution except in the presence of phosphate, potash and nitrate. It is true that in the experiment, a larger growth was made in solutions containing nitrogen and phosphate than in solutions of phosphate and potash or nitrogen and potash, but this growth, at the best, was poor and far from normal. The larger growth is made in the solutions having all the fertilizer constituents and the maximum growth in the solutions containing a higher ratio of potash than of phosphate or nitrogen. The influence of potash in the growth and metabolism of the clover plant is further considered in the next section of this paper, where it is shown that potash is absorbed in larger proportions than phosphate or nitrogen.

## GROWTH AND ABSORPTION

The absorption of the nutrients by both clover and wheat was studied, by analyzing the solutions at the end of each change. The colorimetric methods for determining phosphates, nitrates and potash were used (1). The relation between growth and absorption of the two plants is interesting. The culture jars, arranged in a triangle, in which the plants are growing, and the bottles for storing the solutions for analytical work, are shown in plate 1, figure 3.

These comparative data are given in table 1, which shows the ratio of phosphate, nitrate and potash absorbed from the solution. In the second column is given the original ratio of the solution and in the last column the ratio absorbed by each kind of plant. The solutions which contained only one or two salts are not included in the table; those containing the three salts are given, as these only are of interest in the complete nutrient absorption studies.

The comparison which it is intended should be made in this table is that between the ratio of phosphate, nitrate and potash absorbed by clover, and that absorbed by wheat, from the solution having a similar original ratio. It is seen that in a solution having 50 per cent or more of $P_2O_5$ in its composition (no. 5 to 20) the ratio of potash absorbed by wheat is in general higher than

TABLE 1

*The ratio of phosphate, nitrate and potash absorbed by clover and wheat plants from nutrient solutions containing calcium acid phosphate, sodium nitrate and potassium sulfate—original concentration 80 p.p.m. of $P_2O_5 + NH_3 + K_2O$*

| SOLUTION NUMBER | ORIGINAL RATIO $P_2O_5$—$NH_3$ —$K_2O$ | CROP | RATIO ABSORBED $P_2O_5$—$NH_3$ —$K_2O$ | SOLUTION NUMBER | ORIGINAL RATIO $P_2O_5$—$NH_3$ —$K_2O$ | CROP | RATIO ABSORBED $P_2O_5$—$NH_3$ —$K_2O$ |
|---|---|---|---|---|---|---|---|
| 5 | 80–10–10 | Clover<br>Wheat | 42–36–22<br>46–33–21 | 27 | 40–50–10 | Clover<br>Wheat | 33–53–14<br>29–56–15 |
| 8 | 70–10–20 | Clover<br>Wheat | 34–30–36<br>35–24–41 | 30 | 30–10–60 | Clover<br>Wheat | 20–19–61<br>17–19–64 |
| 9 | 70–20–10 | Clover<br>Wheat | 50–42–8<br>35–49–16 | 31 | 30–20–50 | Clover<br>Wheat | 22–31–47<br>21–34–45 |
| 12 | 60–10–30 | Clover<br>Wheat | 31–31–38<br>28–19–53 | 32 | 30–30–40 | Clover<br>Wheat | 22–29–49<br>19–38–43 |
| 13 | 60–20–20 | Clover<br>Wheat | 41–37–22<br>32–36–32 | 33 | 30–40–30 | Clover<br>Wheat | 21–47–32<br>21–42–37 |
| 14 | 60–30–10 | Clover<br>Wheat | 45–40–15<br>32–51–17 | 34 | 30–50–20 | Clover<br>Wheat | 19–50–31<br>17–58–25 |
| 17 | 50–10–40 | Clover<br>Wheat | 26–21–53<br>24–18–58 | 35 | 30–60–10 | Clover<br>Wheat | 28–59–13<br>23–63–14 |
| 18 | 50–20–30 | Clover<br>Wheat | 31–33–36<br>27–33–40 | 38 | 20–10–70 | Clover<br>Wheat | 17–19–64<br>16–21–63 |
| 19 | 50–30–20 | Clover<br>Wheat | 31–39–30<br>28–41–31 | 39 | 20–20–60 | Clover<br>Wheat | 17–27–56<br>16–37–47 |
| 20 | 50–40–10 | Clover<br>Wheat | 32–42–26<br>33–51–16 | 40 | 20–30–50 | Clover<br>Wheat | 16–37–47<br>15–40–45 |
| 23 | 40–10–50 | Clover<br>Wheat | 36–23–41<br>25–21–54 | 41 | 20–40–40 | Clover<br>Wheat | 13–42–45<br>15–41–44 |
| 24 | 40–20–40 | Clover<br>Wheat | 27–27–46<br>24–32–44 | 42 | 20–50–30 | Clover<br>Wheat | 16–44–40<br>16–48–36 |
| 25 | 40–30–30 | Clover<br>Wheat | 27–33–40<br>22–40–38 | 43 | 20–60–20 | Clover<br>Wheat | 16–51–43<br>18–55–27 |
| 26 | 40–40–20 | Clover<br>Wheat | 28–36–36<br>26–45–29 | 44 | 20–70–10 | Clover<br>Wheat | 20–65–15<br>21–66–13 |
| 47 | 10–10–80 | Clover<br>Wheat | 13–20–67<br>11–18–71 | 51 | 10–50–40 | Clover<br>Wheat | 11–46–43<br>12–46–42 |

TABLE 1—*Continued*

| SOLUTION NUMBER | ORIGINAL RATIO $P_2O_5$–$NH_3$–$K_2O$ | CROP | RATIO ABSORBED $P_2O_5$–$NH_3$–$K_2O$ | SOLUTION NUMBER | ORIGINAL RATIO $P_2O_5$–$NH_3$–$K_2O$ | CROP | RATIO ABSORBED $P_2O_5$–$NH_3$–$K_2O$ |
|---|---|---|---|---|---|---|---|
| 48 | 10–20–70 | Clover | 10–28–62 | 52 | 10–60–30 | Clover | 10–57–33 |
| | | Wheat | 13–38–49 | | | Wheat | 12–52–36 |
| 49 | 10–30–60 | Clover | 8–33–59 | 53 | 10–70–20 | Clover | 9–61–30 |
| | | Wheat | 13–42–45 | | | Wheat | 13–60–27 |
| 50 | 10–40–50 | Clover | 10–38–52 | 54 | 10–80–10 | Clover | 14–66–20 |
| | | Wheat | 11–42–47 | | | Wheat | 17–70–13 |

that absorbed by clover. This group of solutions contains a relatively small proportion of nitrogen and potash but is high in phosphate. In the other solutions, lower in phosphate but higher in either nitrate or potash, the ratio of the constituents absorbed is quite different. The ratio of potash absorbed by clover was greater than with wheat in 19 solutions out of the group of twenty-six. From these culture experiments it becomes apparent that the clover absorbs a smaller proportion of nitrogen and a larger proportion of potash than does wheat.

These data are probably more easily grasped by an examination of figure 3, where the results given in table 1 are shown diagrammatically. The original ratios of these 36 solutions are represented by the origin or junction of the solid and broken line, the location on the diagram corresponding to the scheme previously explained and given in figure 1. The large black dot represents the ratio of the nutrients absorbed from that solution by the clover, and the small circle the ratio of the nutrients absorbed by wheat. The diagram deals only with the ratios of the ingredients and not with the amounts that are absorbed. The dot is connected to its original solution by a solid line and the circle by a broken line. Thus it is possible to see at a glance the ratio of the materials absorbed by the two kinds of plants from each solution.

That the diagram may be fully understood, let us discuss the solution represented by the point at the junction of the lines in the lower right-hand corner of the diagram. This solution is no. 54, as shown in figure 1. From table 1 it is seen that the original ratio of $P_2O_5$, $NH_3$ and $K_2O$ of this solution is 10–80–10. This is also apparent from its location on this diagram. As seen in the table the clover absorbed the $P_2O_5$,$NH_3$ and $K_2O$ in the ratio of 14–66–20. This ratio is located on the diagram (fig. 3) at the black dot which is connected with its original solution by the solid line. The wheat absorbed the three constituents from the original solution in the proportion of 17–70–13, which is located on the diagram at the circle and is connected to the original solution by the broken line. The clover absorbed a higher proportion of potash than did wheat, and the wheat a higher proportion of

nitrogen than did clover. This is shown in the figure by the fact that the dot lies nearer the potash end of the triangle than does the circle. With the exception of the solutions in the high-phosphate, or upper part of the triangle, it is apparent that in most of the solutions the dots lie nearer to the potash end of the triangle than do the circles. This is especially true of the solutions near the center of the triangle which originally contained the potash and nitrate in nearly equal proportions.

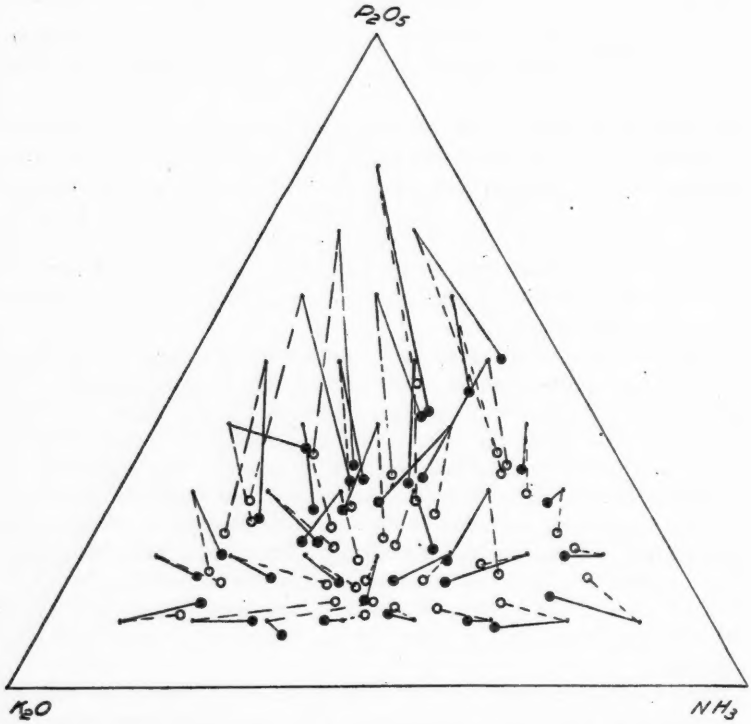


FIG. 3. DIAGRAM SHOWING RATIO OF $P_2O_5$, $NH_3$ AND $K_2O$ ABSORBED BY CLOVER AND BY WHEAT FROM THE NUTRIENT SOLUTIONS OF THE TRIANGLE SET

The points at the junction of the solid and broken line represent the ratio of phosphate, nitrate and potash of the original solution (fig. 1). The circles represent the ratio of the three fertilizing constituents absorbed by wheat, and the black dots the ratio absorbed by clover. The circle is connected to its original solution by a broken line and the dot by a solid line.

Note that in any pair the black dots showing absorption by clover are generally on the left or nearer to the potash angle of the triangle, and the circle showing the absorption by wheat is generally on the right, or nearer the nitrate angle of the triangle.

It would seem that the ratio of absorption of the fertilizing constituents, $P_2O_5$,$NH_3$ and $K_2O$ by clover and wheat are somewhat different, The clover requires a higher proportion of potash, and a smaller proportion of nitrogen than the wheat. The results also indicate that a higher ratio of potash, in a solution containing all three fertilizing constituents, is required for the maximum growth of clover than for the maximum growth of wheat. Conversely, the wheat absorbs and requires for its maximum growth a higher ratio of nitrogen than does clover.

In table 2 the four solutions producing the maximum growth of clover, as recorded in the diagram of figure 2, are given, together with the original ratio of $P_2O_5$,$NH_3$ and $K_2O$ and the ratio of these constituents absorbed. There are also given the four solutions producing the maximum growth of wheat, as recorded in figure 3, page 10, of the article cited (1). Here, too, the original ratio of the constituents and the ratio absorbed by the wheat are presented.

TABLE 2

*The original ratio of $P_2O_5$, $NH_3$ and $K_2O$ and the ratio of these nutrients absorbed by clover and by wheat from the four solutions of each set producing the largest growth*

| CLOVER | | | | WHEAT | | | |
|---|---|---|---|---|---|---|---|
| Solution number | Original ratio: $P_2O_5-NH_3-K_2O$ | Ratio absorbed: $P_2O_5-NH_3-K_2O$ | Green weight | Solution number | Original ratio $P_2O_5-NH_3-K_2O$ | Ratio absorbed: $P_2O_5-NH_3-K_2O$ | Green weight |
| | | | *gm.* | | | | *gm.* |
| 39 | 20–20–60 | 17–27–56 | 3.70 | 33 | 30–40–30 | 21–42–37 | 4.96 |
| 40 | 20–30–50 | 16–37–47 | 3.14 | 41 | 20–40–40 | 15–41–44 | 5.24 |
| 41 | 20–40–40 | 13–42–45 | 3.25 | 50 | 10–40–50 | 11–42–47 | 5.06 |
| 51 | 10–50–40 | 11–46–43 | 3.15 | 51 | 10–50–40 | 12–46–42 | 5.16 |
| Average... | 17–35–48 | 14–38–48 | | Average.. | 17–43–40 | 15–43–42 | |

The solutions producing the maximum growth of clover contained the constituents, $P_2O_5$, $NH_3$ and $K_2O$ in the ratio of 20–20–60 (no. 39), while the solution producing the maximum growth of wheat contained the three fertilizing constituents in the ratio of 20–40–40 (no. 41). The four solutions from the triangle set producing the largest growth of clover, as seen in table 2, contained the constituents in an average ratio of 17–35–48, while the four solutions producing the greatest growth of wheat contained the fertilizing constituents in an average ratio of 17–43–40. Here it is seen that clover requires a higher ratio of potash than of phosphate or nitrogen for its maximum growth, and wheat a higher ratio of nitrogen than of phosphate or potash.

The absorption of the three fertilizing constituents also is interesting. The clover in the four solutions producing the greatest growth absorbed the phosphate, nitrogen and potash in the ratio of 14–38–48, and the wheat absorbed these constituents from its four solutions in the ratio of 15–43–42. The relative absorption of phosphate, nitrate and potash by clover was greater

for potash and the absorption of wheat was somewhat greater for nitrogen. This result is shown not only by the four solutions producing maximum growth just discussed, but is also revealed generally by the data given in figure 3.

The results seem in harmony with the generally accepted idea that clover is a heavy potash-feeding plant and is also in harmony with results secured by the senior author in a field experiment where the triangle fertilizer scheme was used (3). This fertilizer experiment in which acid phosphate, sodium nitrate and potassium chloride were used, was made on Hagerstown loam soil and has been conducted for about 10 years. The composition of the vegetation was originally Canada blue-grass, Kentucky blue-grass, timothy and white and red clover. At the end of 7 years the differently fertilized plots contained the various species in distinctly different proportions. Grass generally has predominated over clover in the plots receiving fertilizers with high ratios of nitrogen, while clover, especially red clover, has been crowded out of such fertilized plots. Clover existed in the struggle more easily in the plots fertilized with mixtures of potash and phosphate, being much more abundant in that section of the triangle.

Therefore, similar conclusions can be drawn from the two experiments, one in aqueous solutions, the other in field plots. In a general way both point to the conclusion that the clover plant requires a higher proportion of potash than of nitrogen or of phosphate, in its metabolism. It should be remembered, however, that the fertilizer requirements of any particular soil will upset this ratio requirement of the plants; the best fertilizer ratio for clover production will vary with different soils. The poor clover soils of the Volusia and Scottsburg series of southern Indiana are most improved for clover production by lime, manure and complete fertilizers. Nitrogen and phosphate appear to be more important than potash. On the other hand, the potato soils of the Cape Charles section of Virginia and of Maine where large amounts of high-potash carrying fertilizers have been used for years, produce clover luxuriantly, undoubtedly in part because of the high potash fertilization.

The results point to the conclusion that normally clover is a potash-loving plant. The true nutrition requirement of the clover plant can be derived from aqueous culture solutions where many factors are controlled. The fertilizer requirements of soils for clover production, where many soil factors play a part, is an entirely different matter. Each soil type, under each soil condition, may have a different fertilizer requirement, making it necessary to study each soil problem separately.

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(2) Schreiner, O., and Skinner, J. J. 1918 The triangle system for fertilizer experiments. *In* Jour. Amer. Soc. Agron., v. 10, p. 225.

(3) Skinner, J. J., and Noll, C. F. 1919 Botanical composition of a permanent pasture as influenced by fertilizers of different compositions. *In* Soil Sci., v. 7, p. 161.

PLATE

## PLATE 1

FIG. 1. Clover in triangle set of nutrient solutions, showing equipment used in the experiment and the greenhouse in which the plants grew.

FIG. 2. Clover grown in nutrient solutions of calcium acid phosphate, sodium nitrate and potassium sulfate and having varying ratios of $P_2O_5$, $NH_3$ and $K_2O$.

*A*, Culture 13 of triangle set, having $P_2O_5$, $NH_3$ and $K_2O$ in ratio of 60–20–20

*B*, Culture 39 of triangle set, having $P_2O_5$, $NH_3$ and $K_2O$ in ratio of 20–20–60

*C*, Culture 43 of triangle set, having $P_2O_5$, $NH_3$ and $K_2O$ in ratio of 20–60–20

*D*, Culture 30 of triangle set, having $P_2O_5$, $NH_3$ and $K_2O$ in ratio of 30–40–30

FIG. 3. Clover in nutrient solution triangle set, showing bottles for keeping solutions for analytical work in the center case, new solutions in the culture jars on the right and the clover cultures growing on the left.

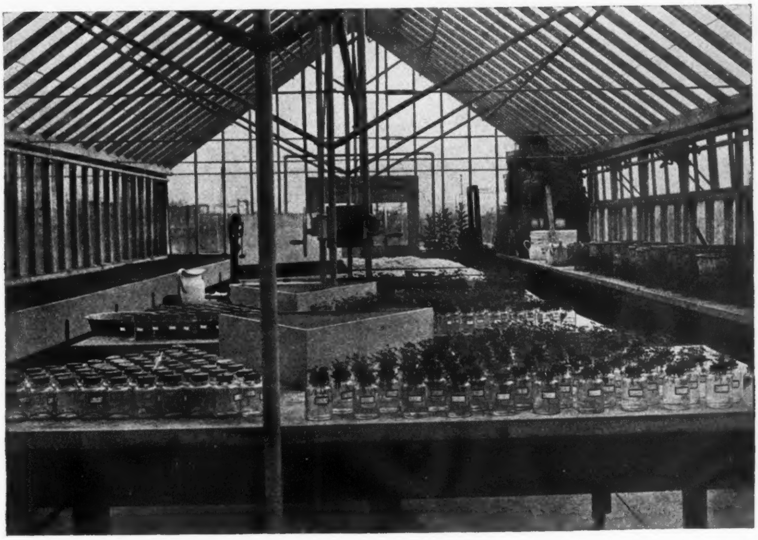

FIG. 1

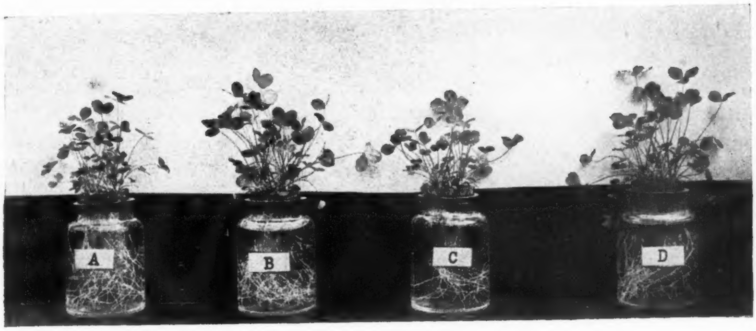


FIG. 2

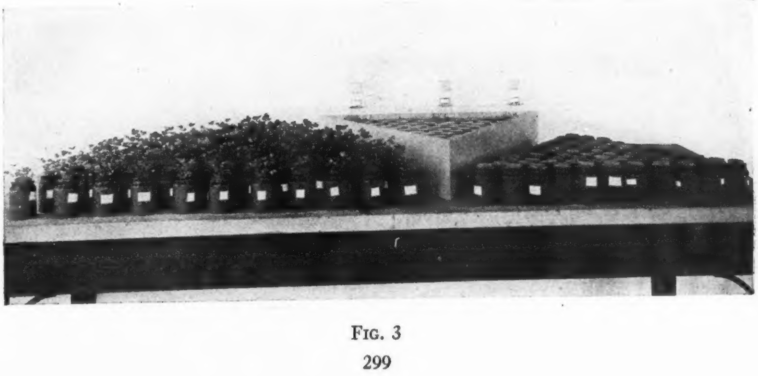

FIG. 3

# NITRIFICATION IN SOME SOUTH AFRICAN SOILS

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## INTRODUCTION

Although the study of the rate and amount of nitrate formation, as a means of judging the biological activity and also the general fertility of the soil, has received a great deal of attention in Europe and America and also some attention in India, Australia and other countries, the writer can find no record of nitrification in soil having received any similar quantitative attention by the agricultural chemists of this country. Juritz (16, 17, 18), Ingle (47), Watt (47, 48), Vipond (47), Marchand (32), and others have all contributed, some very largely, to the amount of data which have been accumulated on the chemical composition of South African soils.

Juritz (16) has published investigations on 40 per cent more soils than all the above mentioned workers together, and using the standard of Maercker as his criterion shows that 52 per cent of the soils of the Cape Province are deficient in nitrogen. Marchand (32) has recently summarized the data accumulated by the investigators of Transvaal soils, and concludes that if a deficiency in nitrogen is assumed, when a soil contains less than 0.1 per cent, then 55 per cent of the soils of this province are deficient in this element. The standards of Maercker and Dyer as used by Juritz and Marchand, are those obtaining in German and English climatic conditions, which are very different from those of South Africa. It has often been observed that the application of mineral nitrogenous fertilizers to soils in South Africa, which are below the European standards in nitrogen content, have not given the expected returns from the fertilizer, and in some cases no returns at all. The only manner of applying nitrogen that has given a monetary return on the soils of this experiment station, has been with legumes as a green manure. Consequently, this station does not recommend to farmers the practice of applying mineral nitrogenous fertilizers except in rare cases. The fact cannot be overlooked that the poverty of the average South African soil in phosphates may be quite sufficient to account for the lack of response of the soil to mineral nitrogenous fertilizers applied alone.

Soils even poor in nitrogen according to European standards often give excellent returns when the rainfall has been sufficient and no nitrogenous fertilizer has been applied.

Hilgard (14) long ago found that Maercker's standard was too high under California conditions.

The writer concurs with Marchand in his opinion that although not sufficient data are at present available for a definite lower standard under these conditions, an arbitrary one might be tentatively adopted.

Marchand gives as his reason that nitrification is very rapid in South African soils, and therefore, a lower nitrogen standard would be advisable. Opinions in general on the intensity of nitrification in semi-arid soils have in the past been based largely on Hilgard's statements of his observations on Californian soils, and the chemists of South Africa have preached that doctrine chiefly on account of the similarity of our climate to that of western America. Later workers in that area have greatly modified the views held by Hilgard, and some differ wholly from them.

Some of the work of the chief investigators of the nitrification problem in western American will be reviewed later on.

## THE OBJECT OF THIS INVESTIGATION

It was with the object of getting some quantitative data on nitrification in South African soils and so a basis for comparing our soils with those of other continents, and ascertaining whether the process of nitrate formation is as active as has been assumed, that the writer undertook the investigations here recorded.

## REVIEW OF SOME PREVIOUS WORK

Watt, as far as the writer can ascertain, is the only investigator who has attempted this problem in South Africa. His work is recorded in the Annual Report of the Transvaal Department of Agriculture, 1907–08. His studies were of a qualitative nature in so far as it has not enlightened us on the amounts of nitrate nitrogen occurring in our soils, but was quantitative in that it gives the time taken for 0.4 gm. of soil to transform the nitrogen, in the modified Winogradsky's solution as used by Hall at Rothamsted, into ammonia nitrite and nitrate. Watt found that nitrification in this solution was complete in 28 to 46 days, and that the two soils that were quickest in this respect contained 1.46 and 1.56 per cent of lime, and 0.141 and 0.174 per cent of nitrogen, respectively. The nitrification of this solution with English soils under similar conditions, he states, was often not complete in 60 days. If then, he concludes, Transvaal soils are so much superior in nitrifying power to English soils under similar conditions, how much more superior must they be during the actual summer months of good rainfall, when the day and night temperatures are considerably higher than those in England? He found that even poor, sandy soils, containing only a little organic matter and a trace of lime nitrified the above solution more quickly than the best English soils. Watt further states, "This would be the explanation of the fact that in the Transvaal

certain soils that would be considered too poor to cultivate in temperate climates, are capable of producing good crops without nitrogenous manuring."

The writer has not corroborated Watt's results with a similar method, as during the last 8 years most soil biologists and chemists have adopted the method of studying the amount of nitrate produced in the soil itself, either from its own nitrogen or together with added nitrogen, and similar methods to these have been used by him, so as to make the results comparable with recent work. Löhnis and Green (26), however, have shown very clearly that when the proper precautions are exercised the solution method gives quite as good an indication of the nitrifying power of the soil as the soil method.

Most of the work on nitrification on semi-arid soils has been done in western America. Hilgard noticed the high amount of nitrate in the alkali soils of California, and attributed it to intense nitrification.

Stewart (43), however, points out that the same causes that accumulated the other water-soluble salts probably accumulated the nitrates, and gives instances of observations of high amounts of nitrates recorded in Turkestan, India and China, but always associated with correspondingly high amounts of other water-soluble salts, while Hilgard attributed the high amount of nitrate to the nitrification of organic matter taking place at the present time. Headden (12, 13) concludes that the high percentage of nitrate in the brown spots on arable land in Colorado is due to the fixation of atmospheric nitrogen *in situ* and the subsequent nitrification of the dead bacterial flora. These processes, he says, are going on actively today.

It is a significant fact, though, that Headden's analyses of the water-soluble salts of the soils studied, show high percentages of chlorides and sulfates. Still, he determined that large amounts of nitrogen are fixed, if soils from some of these nitre spots are left in the laboratory at a suitable moisture content.

The amount of nitrogen fixed according to Headden and Sackett (39) amounts in some cases to thousands of pounds per acre.

Stewart (43) in Utah, with climatic and soil conditions similar to those of Colorado, found that nitrification added only 28 pounds of nitric nitrogen per acre per annum, and he quotes Warington as giving 86.5 to 89.5 pounds per acre as the amount formed under humid conditions at Rothamsted, while the highest amount the writer has observed in cultivated fallow non-irrigated land at Potchefstroom in a year, has been 84.9 pounds per acre foot. At no time on the irrigated plots did he find as much as this, while the nitrate found on alkali irrigated soil at Klerksdorp amounted to only 23.6 pounds per acre foot, with the total water-soluble salts per acre foot as 13,200 pounds. Stewart also found in the shale cliffs from which some of the soils of both Colorado and Utah are formed 66 to 354 parts per million of nitrate, and in some places 2000 parts per million (43, 44). This he states is sufficient to account for the high nitrate content of the soils. Shales in South Africa around Prieska and Hay have been found to contain potassium nitrate in large quantities, 0.06 to 9.97 per cent; the origin is doubtful but it is thought that it may have been

derived from the nitrification of the excrements of birds and small animals, and have accumulated through centuries, the rainfall of the area being low (9).

Stewart (42) found in other parts of Utah only small quantities of nitrate in soils not containing other water-soluble salts, many having less than 1 part per million of nitric nitrogen, the highest containing only 4.5 parts per million, and most having not more than 2.4 parts per million. This is strongly in accordance with the amounts of nitric nitrogen found in field samples of various South African soils by the present writer. The writer in the summer of 1913 spent considerable time on several of the ranches from which Stewart took samples, and found the nature of the soil, the method of cultivation and fallowing under 18 inches of rainfall such as to encourage maximum nitrification. Also, the crops of wheat and barley produced were far above our averages in South Africa.

Stewart and Greaves (44) also worked on irrigated Utah soil, ideal for nitrigen fixation and nitrification and giving strong cultures of *Azotobacter;* they did not get anything like the increases in nitrates that are reported by Headden. They point out that in a great many cases where Headden records increases in nitrates, his own figures show increases in chlorides as well. They do not deny that there may be very intense nitrogen fixation in Colorado soil, but from Headden's own results they have correlated the nitrogen and chlorine and say that any explanation that accounts for increases in nitrates must also account for increases in chlorides, and on that account the explanation of fixation from the atmosphere will not suffice.

Sackett (39), however, shows that the rate of the fixation of nitrogen by soils from these brown nitre patches is sufficient to account for all the nitrates found, if all the nitrogen that is fixed is nitrified. Again in 1914 he maintains that the nitrates are formed *in situ* and cannot be accounted for by the amount of nitrate in the irrigation water which is only 0.1 to 0.6 part per million. Neither does the drainage water from soils with rich nitre patches contain more than a trace of nitrate, so Sackett concludes the nitrates are not accumulated from water by surface evaporation (40). He has also shown in his second mentioned work that Colorado soils have excellent nitrifying powers, and in comparing them in this respect with soils from other sections of the United States found the Colorado soils to be much superior in the nitrifying of dried blood, ammonium chloride, carbonate and sulfate. Even then he does not think that this active nitrification could account for the excessive accumulations of nitrate, as Colorado soils are deficient in organic matter. Hutchinson (15) shows very clearly that nitrogen fixation can be increased by adding nitrogen-free organic matter to the soil, and thus it would seem that the lack of organic matter in Colorado soils might also be a factor against excessive fixation.

Headden in 1918 says that he has now too many instances at his disposal to entertain the idea that the high nitrate content of the shales is sufficient to explain the nitre spots in Colorado soils; some of these spots occur hundreds

of feet above the shale, others below it and others nowhere near shale beds (13). He also states that nearly all the irrigation waters are very low in nitrate content, and is still firmly convinced that the nitrogen gets into the soil by direct fixation in these nitre spots which contain more active bacteria than have been hitherto found in other parts.

The only instance of which the writer knows of an exceptionally high nitrate spot in a South African soil is that mentioned by Juritz in the Colesburg area, which contained 0.3 per cent of total water-soluble salts including 0.105 per cent of calcium nitrate and 0.086 per cent of magnesium nitrates (17).

Buckman (5) working on non-irrigated land in Montana, found in cultivated fallow nitrates up to 66.5 parts per million. Scott and Robertson (36) in Australia report nitric nitrogen at the rate of 24 parts per million in fallow land.

Recently Prescott (35) in Egypt reports 35 parts per million of nitric nitrogen in fallow land, but on the ridges of irrigated land he found 601 to 697 parts per million. This, however, was always accompanied by large quantities of other soluble salts. Tulaikoff (46) in a section of semi-arid Russia did not find more than 22 parts per million of nitric nitrogen in fallow soil, as a 5-year average.

The workers on Colorado soils are the only ones of whom the writer is aware who report such excessive quantities of nitrate in soil, which nitrate is not associated with quantities of other water-soluble salts, or heavily impregnated irrigation or seepage waters.

By far the most work that has been done on comparing the nitrifying powers of humid and arid soils is that by Lipman, Burgess and Klein (24). These investigators are of opinion that the nitrifying powers of arid soils are no more intense than those of humid regions, while they admit their data are not quite positive, the conclusion seems possible that the humid soils are better. If the efficiency of the two lots of soils is compared only on the percentage of the soil nitrogen oxidized, this conclusion can be drawn.

It would seem that the amounts of nitrate recorded by workers on arable soils in semi-arid regions in general are low, when compared with high amounts found in the humid region of Ithaca, New York, by Lyon and Bizzell (28). In making this statement the writer excepts the high amounts found in nitre spots, and these amounts associated with quantities of other water-soluble salts on alkali soils. Lyon and Bizzell found in their seasonal variation studies on bare soil 180 parts per million frequently and often over 200 parts per million.

On semi-arid lands the highest figure of which the writer knows, is that of Buckman in Montana, with 66 parts per million and the writer found in midsummer in Potchefstroom, 55 parts per million.

## OUTLINE AND SCOPE OF THIS WORK

Before further discussing the problem the writer will record the results of his own investigations, which bear also on other points besides those of inten-

sity of nitrification. In broad outline the purpose and scheme of the work was to study and obtain data on some of the following phases of nitrification under South African conditions:

1. To ascertain the amount of nitric nitrogen in the soil around Potchefstroom, virgin, cropped and cultivated at various seasons of the year and after various crops.
2. To correlate the seasonal variations of nitrates with our climatic conditions.
3. To ascertain the amount of nitric nitrogen in the first 5 feet of the soil in various sections of this locality.
4. To compare the nitrifying powers of each of the 5 feet, and see how far nitrification is active.
5. To see how much limestone and slaked lime affected nitrification on dry-land plots growing potatoes.
6. To compare the nitrifying powers of our irrigated and long cultivated land with virgin dry lands, in regard to various amounts of blood-meal and ground limestone applied.
7. To find out how much nitric nitrogen was added to a soil by cowpeas alone, lime alone, and by mixtures of the two.
8. To compare the nitrifying powers of soils from diverse parts of the Union with one another, and to ascertain the nitrogenous fertilizer most easily nitrifiable.
9. To compare the nitrifying powers of virgin and cultivated soils of the same type.
10. To correlate, if possible, the nitrifying power of soils with the amount of rainfall in the area from which they came, and also with the organic matter, total nitrogen content, and lime requirement.
11. To compare the nitrifiability of whale guano variously treated.
12. To compare the nitrifiability of small and large amounts of nitrogenous fertilizers, and to ascertain if possible which is better for comparing the nitrifying powers of various soils.

## EXPERIMENTAL PROCEDURE

As the writer had had considerable experience in the manipulation of the phenol-disulfonic acid colorimetric method of determining nitrates, while working in the soil technology laboratories of Cornell University, this method was selected for use in these investigations. The method is very quick and also accurate. It is described in Bulletin 31 of the Bureau of Soils (41). It is endorsed by Lipman and Sharp (25), Kelly (19) and Noyes (34), and is used by Lyon and Bizzell (30) and many other workers in this field.

Kelly compared this method with that of the aluminum-reduction method as outlined by Burgess (6), and found that it was in every respect as accurate and in some cases more accurate.

The method used at first was as outlined in Bulletin 31, but later on the Pasteur-Chamberland filter tube got broken, and as another could not be secured the Noyes modification was adopted. Both Noyes, and Lipman and Sharp show in their papers that clarifying the soil solution with slaked lime before filtering does not interfere at all with the accuracy of the nitrate determination, and the writer finds this method considerably quicker than the filter-tube one, unless a whole battery of filter tubes are at one's disposal.

## METHOD OF SAMPLING IN FIELD

The soil at this station becomes so hard and dry during a large part of the year, that it is very unsatisfactory and in fact practically impossible to use a soil auger. A pick and spade were used in taking all the samples. Four holes were dug diagonally across a $\frac{1}{20}$-acre plot, each 1 foot deep. A vertical slice of soil about $1\frac{1}{2}$ inches wide was cut off from the side of the hole and placed on a clean rolling cloth, the four slices were passed through a $\frac{1}{4}$-inch mesh sieve and thoroughly mixed by rolling, and a representative sample placed in a glass screw-top fruit jar, and conveyed immediately to the laboratory, where the moisture content and the nitrate content were determined.

## I. PRELIMINARY STUDIES

A number of preliminary studies are recorded in table 1. These determinations were made to obtain some idea of the amount of nitric nitrogen, in the soil on various portions of the farm at this station before the experiments proper were started. This was early in June, 1919, and the cold weather had already set in. Soil from a dry-land virgin plot—from two separate samples taken on June 1, gave nitrates in small quantity but in very close agreement. During this cold month the nitrates had actually increased from 0.48 to 2.9 parts per million of nitric nitrogen, as will be seen by the determinations made on June 1 and 30 from the same spot.

The soil from the cultivated irrigated soil on June 30 contained only 0.44 parts per million of nitric nitrogen while the soil on the dry-land cultivated plots of the same type as the dry-land virgin had 38 parts per million on June 10 and 18 parts per million on July 11, 1919. This shows the benefits from cultivation and the increased water-holding capacity of the soil on nitrate production. The nitrates in the cultivated soil have decreased during this dry, cold period. There was only 0.04 inch of rainfall in May, 1919, and 0.03 inch in June of the same year. The air temperatures were a mean maximum of 73.8°F., a mean minimum of 37.1°F. and a mean temperature of 55.4°F. during May; and for June a mean maximum of 72°F., a mean minimum of 34.6°F. and a mean temperature of 53.3°F.

The day temperature would not stop nitrate production but the lack of moisture was so great, and the actual moisture content of the virgin soil so much lower than that of the cultivated, that it is surprising that a small increase in nitrate in the virgin soil is recorded, where the cultivated soil has decreased in that respect.

A similar strange behaviour of the dry-land virgin soil will be noticed in figure 1, illustrating seasonal variation. This plot shows a rise in nitrates just at the time all the other four plots show a big fall, only this takes place at the height of the rainy season instead of in the dry winter period. This point will be discussed again.

TABLE 1

*Preliminary studies*

| DATE | LOCALITY | PLOT NUMBER | SOIL MOISTURE | NITRIC NITROGEN | TREATMENT PER ACRE AND REMARKS |
|---|---|---|---|---|---|
| *1919* | | | *per cent* | *p.p.m.* | |
| June 1 | Dry land, virgin soil near football field | | 7.0 | 0.48 | Soil very hard and difficult to sample |
| | | | 6.0 | 0.47 | |
| June 30 | Dry land, virgin soil near football field | | 3.0 | 2.9 | |
| June 30 | Soil from cultivated and irrigated land | | 2.7 | 0.4 | This soil had not been irrigated for many months and had grown sorghums |
| June 10 | Dry land, experiment plots, potato series | 1 | 8.1 | 27.6 | 8 tons farm manure |
| | | 2 | 8.6 | 45.0 | Control |
| | | 3 | 8.9 | 34.5 | 70 lbs. $K_2SO_4$, 150 lbs. dried blood, 200 lbs. super |
| | | 4 | 8.3 | 33.4 | 70 lbs. $K_2SO_4$, 200 lbs. super |
| | | 5 | 8.2 | 24.4 | 150 lbs. dried blood, 200 lbs. super |
| | | 6 | 7.0 | 38.6 | Control |
| | | 7 | 6.9 | 32.6 | 150 lbs. dried blood, 70 lbs. $K_2SO_4$ |
| | | 8 | 5.7 | 30.9 | 70 lbs. $K_2SO_4$ |
| | | 9 | 6.9 | 38.6 | 200 lbs. super |
| | | 10 | 6.2 | 32.1 | Control |
| | | 11 | 6.6 | 48.5 | 150 lbs. dried blood |
| July 11 | Dry land, experiment plots, potato series | 2 | 6.5 | 20.4 | Control |
| | | 3 | 6.8 | 21.4 | 70 lbs. $K_2SO_4$, 150 lbs. dried blood, 200 lbs. super |
| | | 6 | 7.0 | 18.2 | Control |
| | | 9 | 7.1 | 22.8 | 200 lbs. super |
| | | 11 | 7.3 | 22.7 | 150 lbs. dried blood |
| July 4 | Dry land, experiment plots, maize section | 5 | 5.0 | 5.3 | 150 lbs. super |
| | | 7 | 5.3 | 5.9 | Control |
| | | 10 | 5.3 | 6.3 | 500 lbs. Saldanha Bay phosphate, 75 lbs. dried blood |
| | | 12 | 4.7 | 6.0 | 75 lbs. dried blood |
| | | 15 | 4.5 | 6.6 | Control |

If table 1 is consulted, it will be seen that on June 10 the soil of the dry-land potato plots had a good nitrate-nitrogen content, but that the five plots that were repeated a month later showed a distinct decrease in nitrates. The nitrates on five maize plots on an adjoining series show a much lower nitrate content than the potato plots. Both crops had been harvested in the middle

of May, but it is possible that the increased aeration caused by the plowing up of the potatoes may account for the greater nitrate content of the soil, although the samples were not taken in the plowed tracts, but between them. Again, potatoes do not use as much nitrogen as maize, and relatively the maize crop was better than the potato crop. There does not appear to be any definite, inverse relationship between the amount of nitrate found on the plots and the yields of the crop. These figures are at the disposal of the writer, but as they have not been published and are not his own work, they are not included in this paper.

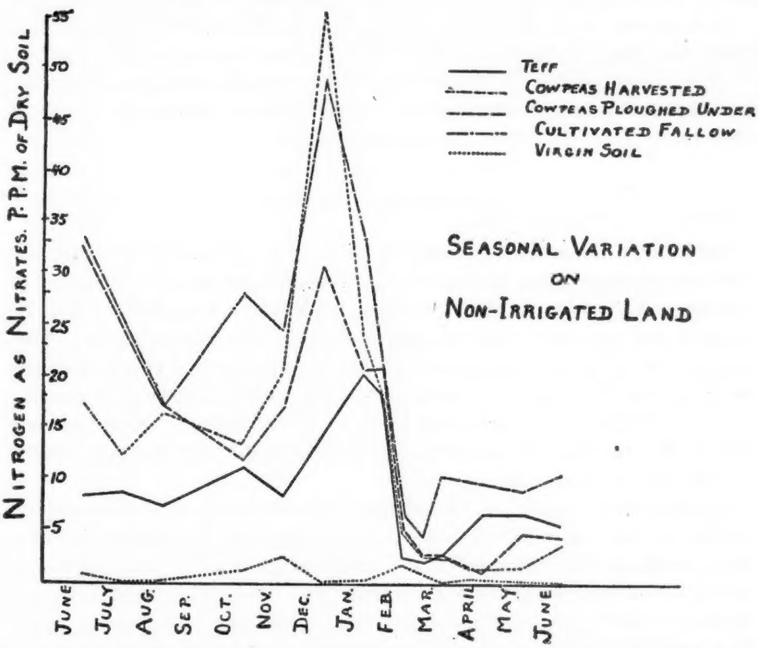


FIG. 1. SEASONAL VARIATIONS IN NITRATES, ON VIRGIN SOIL, CULTIVATED FALLOW LAND AND CULTIVATED CROPPED LAND, 1919–20 (table 3)

The nature of the fertilizers which the plots received does not appear to have affected the subsequent nitrate content; even the addition of 150 pounds of dried blood per acre has not increased the nitrate content above that of the check plots, with the exception of that on plot 11.

Plot 1, receiving 8 tons of stable manure per acre, does not show as good a nitrate yield as the controls. This was the first year that this land had been planted to a crop, and the physical condition of this plot, judging from the difficulty in sampling it, was not as good as that of the other plots, so this may be explained by lack of proper aeration. Lyon and Bizzell (28) record

higher nitrate contents in soil that had carried maize than unplanted soil, but the writer found 34.8 parts per million of nitric nitrogen on the fallow strip beside the maize plots at the end of the season, the highest of which contained 8.7 parts per million. Their figures also show that the potato soil was next highest in nitrates, while the writer's show that the potato soil was far ahead of the maize, and just about equal to the fallow soil beside it. A great deal of work would have to be done on this subject, though, to obtain results comparable to theirs in amount of data. An important fact must not be overlooked, i.e., on July 4, the maize plots contained less moisture than the potato plots did on July 11, and no rain had fallen in the meantime.

McBeth and Smith in Utah found that no increases in nitric nitrogen took place when the soil moisture content had reached 5 per cent (33).

They found too that the nitrifying power of soil that had grown potatoes was slightly better than that of soil which had grown maize, and that both were better than the fallow land in this respect.

## II. SEASONAL VARIATION

On June 16, 1919, the first samples were taken on the dry-land fertilizer and crop rotation plots, with a view to studying the seasonal variation on non-irrigated land under Potchefstroom conditions. On account of other duties it was possible to take samples on the plots only once monthly. During the most active growing period for maize in February and March, however, sampling was done every two weeks. The soil on which these plots are situated is a reddish brown, fine sandy loam, which becomes very hard and compact in dry weather. It has a nitrogen content of 0.09 per cent and contains 6.7 per cent of organic matter.

By referring to tables 2 and 3 and figure 1 it will be seen that the study was carried on over the period of a year, on five different but adjacent pieces of land, which are designated as "teff," "cowpeas harvested," "cowpeas plowed under," "cultivated fallow" and "virgin soil." From the same tables and figure 6 it will be seen that seasonal variation was also studied for a shorter time on additional plots termed "maize after maize," "teff after maize," "uncultivated fallow," "cowpeas plowed under after teff."

There are four strips of land termed *A*, *B*, *C*, and *D* each divided into 17 $\frac{1}{20}$-acre plots, on which a rotation of maize, maize, cowpeas and teff is practised. On thirteen of the cowpea plots the crop is cut for hay, and on four of them it is plowed under as a green manure. As a system of fertilizing is also practised the samples for nitrate work were taken only on the control plots.

When this study was started in the winter of 1919 the range *A* called "teff" had just grown that grass for hay, on range *B* called "cowpeas harvested," the crop had been cut for hay, while on that termed "cowpeas plowed under," the cowpeas were used as a green manure. "Cultivated fallow" was a plowed and harrowed strip between *A* and *B*, or "teff" and "cowpeas," while the

virgin strip was along the outside of the plots. These names are followed throughout in order to avoid confusion, as the nitrates were determined on the same plots the whole year, but it must be borne in mind that the crop changed. For example, the "teff" section carried cowpeas, while the cowpeas were followed by maize in the middle of the season. Table 2 makes this clear.

By referring to figure 1 it will be seen that from June to July four of the five strips of land under observation show a decrease in their nitrate-nitrogen content, the "teff" only remaining about constant. This general decline corresponds somewhat with the downward temperature curve, for the cold dry months of June and July, as shown in figure 4.

Four of the plots show a continued decrease throughout August, "cowpeas harvested" alone showing an increase, which corresponds to the upward curve of the temperature record in that month. All during September and October,

TABLE 2

*Planting and cultivating record*

| RANGE | SEASON 1918–19 | SEASON 1919–20 | PLOWED | PLANTED | RATE PER ACRE | CULTIVATED | HARVESTED |
|---|---|---|---|---|---|---|---|
| | | | | | *lbs.* | | |
| A | Teff | Cowpeas | Nov. 14, 1919 | Nov. 22, 1919 | 20 | Dec. 12, 1919<br>Feb. 19, 1920 | Feb. 4, 1920 |
| B | Cowpeas | Maize | Nov. 14, 1919 | Nov. 22, 1919 | 15 | Dec. 12, 1919<br>Feb. 19, 1920 | May 26, 1920 |
| C | Maize | Maize | Nov. 14, 1919 | Nov. 22, 1919 | 15 | Dec. 12, 1919<br>Feb. 19, 1920 | May 26, 1920 |
| D | Maize | Teff | Nov. 14, 1919 | Nov. 22, 1919 | 6 | Nil | Feb. 20, 1920 |

however, this plot falls again almost to its July level. "Cowpeas plowed under" also decreased from June to the end of October, while during September and October the temperature rises, reaching its third highest crest of the year. There is also an increase during this time of the nitric nitrogen in the "virgin," "teff" and "cultivated fallow" plots. There was 0.15 inch of rain in the second week of September, which does not even show in the soil-moisture curves (fig. 2), and can hardly be responsible for the gain of these three plots. The "teff" and "fallow" plots show a depression in November, while the virgin continues to rise. Both cowpea plots also show a steep rise in November, the first month of good rain. The virgin soil reached its highest level at the end of November. During December there is a steep rise for all except the virgin strip which is again declining. "Cultivated fallow," "cowpeas harvested" and "cowpeas plowed under" reach their highest level by the end of December, before the maximum temperature curve is reached in January. The "teff" plot is the only one which reaches its maxi-

TABLE 3

*Seasonal variation in nitric nitrogen on non-irrigated land, dry soil; June, 1919, to June, 1920*

| PLOT AND RANGE | JUNE 16 | JULY 25 | AUGUST 27 | OCTOBER 2 | NOVEMBER 6 | DECEMBER 9 | JANUARY 9 | FEBRUARY 4 | FEBRUARY 26 | MARCH 4 | MARCH 17 | APRIL 8 | MAY 6 | JUNE 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m* | *p.p.m.* |
| Virgin | 1.0 | Nil | Faint trace | 1.0 | 2.3 | Nil | Trace | Faint trace | 1.6 | Nil | Nil | 0.4 | Trace | Trace |
| Teff (A) | 8.3 | 8.7 | 7.3 | 11.1 | 8.3 | 14.6 | 20.0 | 14.1 | 2.4 | 2.0 | 2.7 | 6.4 | 6.5 | 5.3 |
| Cowpeas harvested (B) | 17.4 | 13.3 | 16.2 | 12.5 | 20.1 | 55.3 | 24.0 | 18.4 | 5.0 | 2.5 | 2.1 | 1.2 | 1.4 | 3.7 |
| Cowpeas plowed under (B) | 32.6 | 16.1 | 17.1 | 11.9 | 16.9 | 30.9 | 20.6 | 20.7 | 5.2 | 2.8 | 2.6 | 1.0 | 4.7 | 4.5 |
| Cultivated fallow | 34.8 | 24.6 | 16.2 | 28.2 | 25.6 | 49.0 | 33.5 | 20.7 | 6.5 | 4.4 | 10.2 | 9.5 | 9.0 | 10.3 |
| Uncultivated fallow | | | | | | | 16.1 | | | | | 5.5 | 6.0 | 10.7 |
| Maize after maize (C) | | | | | | | 16.1 | 10.0 | 1.2 | 3.4 | 1.8 | 1.7 | 2.7 | 3.4 |
| Teff after maize (D) | | | | | | | 18.5 | 5.1 | Trace | 1.8 | Nil | 0.2 | 1.5 | 1.7 |
| Cowpeas plowed under after teff (A) | | | | | | | | | 4.9 | 5.3 | 4.9 | 16.3 | 13.2 | 11.1 |

TABLE 4

*Moisture of non-irrigated soils, showing seasonal variation, June, 1919, to June, 1920*

| PLOT AND RANGE | JUNE 16 | JULY 25 | AUGUST 27 | OCTOBER 2 | NOVEMBER 6 | DECEMBER 9 | JANUARY 9 | FEBRUARY 4 | FEBRUARY 26 | MARCH 4 | MARCH 17 | APRIL 8 | MAY 6 | JUNE 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| Virgin soil | 7.7 | 7.0 | 6.4 | 5.1 | 9.7 | 8.3 | 9.0 | 10.4 | 13.1 | 12.4 | 10.6 | 8.9 | 7.4 | 7.9 |
| Teff (A) | 6.4 | 5.9 | 5.2 | 3.5 | 9.5 | 10.8 | 10.1 | 10.6 | 13.1 | 11.4 | 11.0 | 9.9 | 8.9 | 8.9 |
| Cowpeas harvested (B) | 6.7 | 6.9 | 5.6 | 5.6 | 9.5 | 10.8 | 11.2 | 11.5 | 13.0 | 11.4 | 10.6 | 9.9 | 8.6 | 8.6 |
| Cowpeas plowed under (B) | 7.2 | 7.4 | 6.0 | 4.5 | 9.9 | 10.3 | 9.6 | 10.6 | 13.2 | 11.3 | 10.9 | 9.2 | 8.0 | 9.0 |
| Cultivated fallow | 8.8 | 9.5 | 7.7 | 7.0 | 10.6 | 8.8 | 8.9 | 11.5 | 13.9 | 12.5 | 11.6 | 11.3 | 10.7 | 10.7 |
| Uncultivated fallow | | | | | | | | | | | | 5.9 | 10.1 | 10.4 |
| Maize after maize (C) | | | | | | | 9.1 | 11.3 | 12.9 | 11.6 | 9.7 | 7.9 | 8.1 | 8.2 |
| Teff after maize (D) | | | | | | | 8.2 | 9.4 | 12.0 | 10.8 | 9.1 | 7.4 | 6.0 | 7.9 |
| Cowpeas plowed under after teff (A) | | | | | | | | | 13.2 | 12.4 | 13.5 | 11.4 | 8.7 | 10.0 |

mum at the end of January, after the temperature maximum, while the three just previously mentioned are showing a steep downward fall. During the last few weeks of February there is a uniform and steep drop for all the plots, excepting the virgin. This sudden decrease in nitric nitrogen is shown also in the additional plots studied, and plotted in figure 6. The virgin soil attains a second crest at the end of February, while all the other plots are about at their lowest ebb.

This was a very active growing time, and it might at first be supposed that the nitrates had been strongly drawn upon by the crops, but by reference to table 2 it will be seen in range *A* called "teff" in figure 1, the cowpeas had

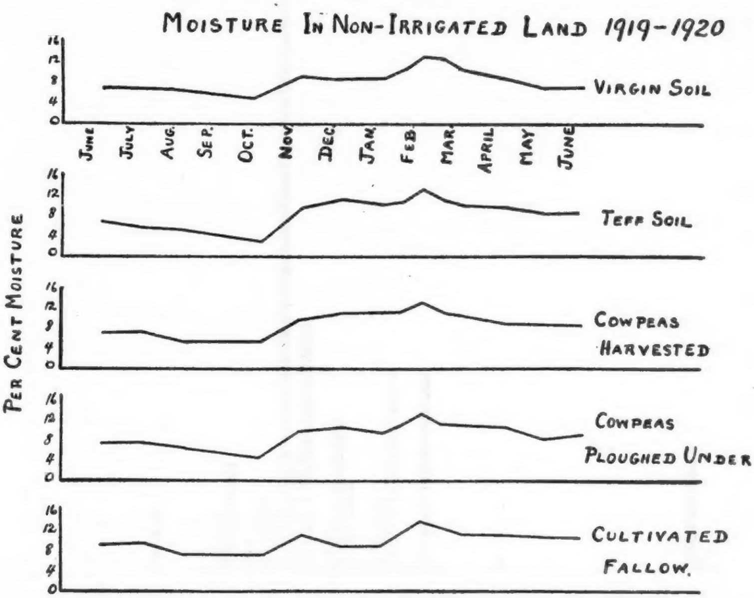


FIG. 2. MOISTURE CURVES OF THE STRIPS PLOTTED FOR NITRATES IN FIGURE 1 (table 4)

been harvested on February 4, 1920, and further the fallow land also shows this great decrease. On this account we cannot attribute the steep drop to crops. From the end of the first week in January to the end of the first week in February, there is a fairly steep drop in temperature, but not sufficient to retard nitrification greatly or account for the lessening of the nitrates. This sudden fall in nitrates, in January and February particularly, corresponds much more closely to the rainfall in those months, than it does to the drop in temperature. In fact, the nitrate curves on the whole fit the rainfall diagram better than they do the one for temperature. If the soil-moisture curves are consulted (fig. 2) it will be seen that there is a steep rise in November, after

which the greatest amount of nitrates was found. Again the highest crests in the soil-moisture curves correspond to the lowest in the nitric-nitrogen diagram. It was after the good rainfall in the first week in November that these plots show a good rise. There was again 1.8 inches of rain the last week in November, and this is followed by 0.7 inch the first week in December. There is then a 2-week period with only 0.09 inch of rain, the temperature is high, the soil moist, in fact conditions are ideal for nitrification. By the end of December the greatest increase is found in the nitrates, in spite of the 0.95

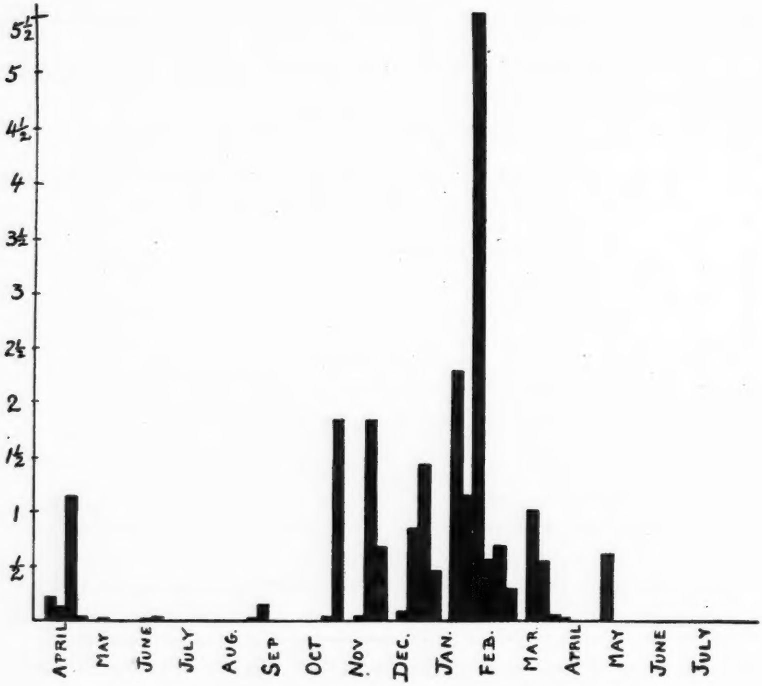


FIG. 3. WEEKLY RAINFALL IN INCHES, 1919–20

inch of rainfall in the last week, which may have washed some nitrates below the first food zone. The week after this highest crest in the nitrates was reached, i.e., the first week of January, there was a rainfall of 1.5 inches and it is after this and the 2.3 inches the last week in January that the rapid decrease in nitric nitrogen is noticed. The first week in February had 1.15 inches of rain and the second week was the rainiest of the season with 5.68 inches. It is after this downfall that there is the very uniform drop in six plots (fig. 1 and 6).

This decrease can be attributed largely to the heavy rains in February, and if table 15 is referred to, it will be seen that in cases 1, 2 and 4, representing depth samples taken at different parts of the plots under study, no nitrates are recorded in the fourth foot and in case 7, only traces of nitrates were found in the fifth foot in January.

No. 8, "maize after maize," was sampled on February 3, 1920, and contained 21 parts per million of nitric nitrogen in the first foot, 1.2 in the fourth, and nil in the fifth. On February 20 this same plot was again sampled, 6 inches of rain having fallen in the meantime, and only 5.3 parts per million were found in the first foot, while the fourth foot contained 12.7 parts per million and the fifth foot 8.4. The evidence is such as to leave little doubt

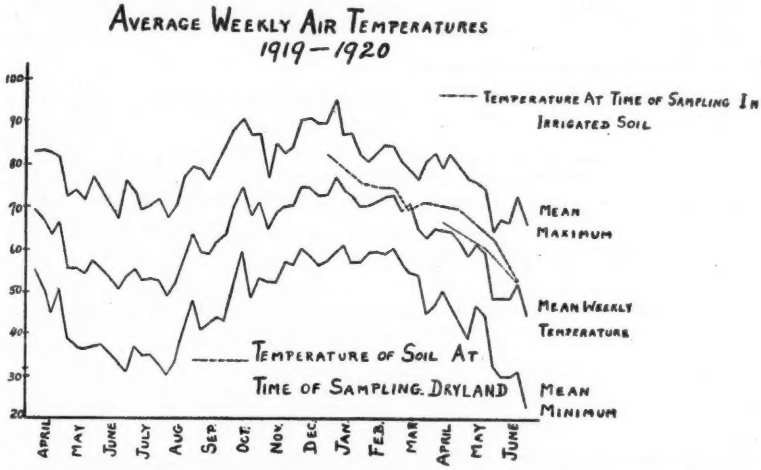


Fig. 4. Average Weekly Air Temperature, 1919–20. Also Soil-Temperature Curve for 6 Months on Dry-Land Soil at the Time of Sampling, and for 3 Months on Irrigated Land

that the very uniform and rapid decrease in the nitrates in February can be attributed to the heavy rains.

After this exceedingly rapid decrease there is still a further decrease until the middle of March, and during the latter two weeks of March the "cultivated fallow" has again risen 6 parts per million, and the "teff" strip, on which the cowpeas had been cut on February 4 also shows a rise. The virgin land with grass, and the cowpea strips growing maize decrease steadily, the latter two reaching about 1.0 part per million at the end of the growing season. There is no doubt that these decreases, while the bare strips are increasing, are due to the nitrates being used by the crops. After the end of April when the maize is ripe, there is again a rise on their nitrate content. The "maize after maize" plot (fig. 6) also shows the rise.

During the last week in May there were killing frosts, yet the two plots which had previously reached the highest two crests recorded in this investigation, show a decided rise after this and during the subsequently colder month of June. Figure 6 shows this rise, also on three of the four plots after some of the coldest weather experienced during the whole year, the uncultivated fallow making the most rapid rise. Five of the seven plots of the limed

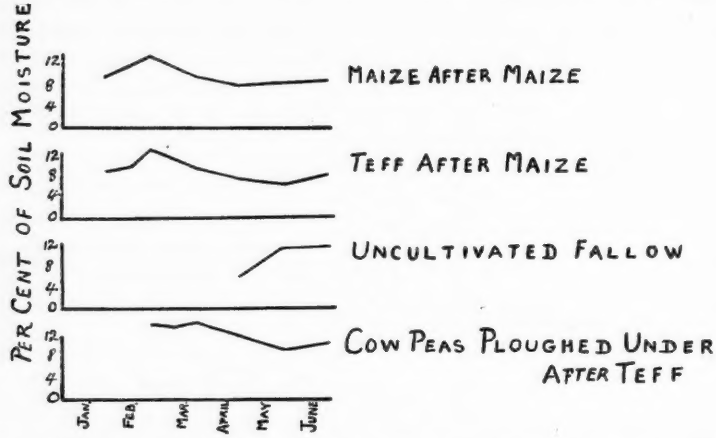


FIG. 5. MOISTURE CONTENT OF SOIL PLOTS STUDIED FOR NITRATES FOR A LESSER TIME

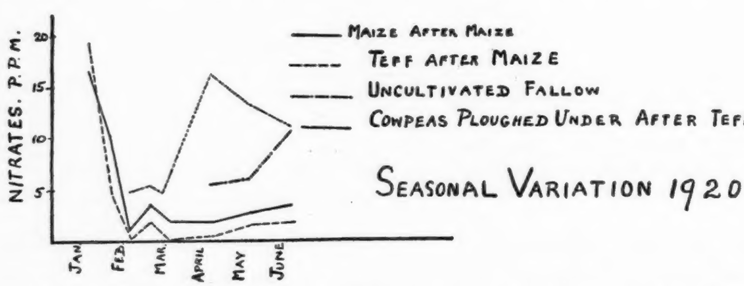


FIG. 6. THE NITRATE CURVES FOR THE SOIL PLOTS STUDIED FOR NITRATES FOR A LESSER TIME

potato series also show a very distinct rise in June. This may perhaps be explained by the biological theory of partial sterilization of Russell and Hutchinson which they apply to heated soils.

The frost, like the heat, may kill the protozoa and other enemies of nitrifying bacteria, which then become more active, and an increase in nitrates is found as a result. The low moisture content of the soil and the low temperatures prevailing at that time of the year, however, are not conducive to

very active nitrification. This is a point which the writer intends to investigate further as this rise in the nitrate curves corresponding to the lowest temperature curve, and the absence of rainfall is indeed striking.

The sudden rise in nitrates in November and December after the first good rains, also may be due to partial sterilization by drought and heat, e.g. the temperature of cultivated dry soil on October 19, 1920, was 35.5°C. and last year the soil was even drier.

Conn (7) obtained the highest counts of bacteria of the whole year from the frozen soil, and Brown and Smith (4) in the main confirm his work.

### *The behavior of the virgin soil*

The virgin soil remains uniformly the lowest in nitric-nitrogen content throughout the year. It was also hard and compact even in the rainy season, and the most difficult to sample all the year round, the pick being used more often than the spade. Bad aeration may be put down as the factor most detrimental to nitrification. A strip of virgin land adjacent to that on which the virgin-soil samples were taken the whole year through, was sampled on January 13, 1920, just before plowing, and contained 1 part per million of nitric nitrogen. It was afterwards cultivated and planted to potatoes. Eighteen days later the check plot of this strip had increased to 39.8 parts per million, showing how effective is aeration combined with sufficient soil moisture and a high temperature for nitrification. The unplowed land again analyzed for nitrates at this time showed only a trace.

The virgin soil shows a steady and gradual rise in nitrate content from August, despite the low moisture content, which decreased until the end of October. In this respect the upward nitrate curve conforms with that of temperature rise. After the first November rains the curve rises at once more steeply, and attains its maximum at the end of that month, after a rainfall of 3.8 inches.

By the end of December there is only a trace of nitrate and this state of affairs continues all through January. In February there is again a rapid rise, and the virgin soil attains its second highest crest at the end of that month. This corresponds to the time that all the others dropped to almost their lowest nitrate content. The heavy rains were not absorbed by the compact soil as was done by the cultivated strips, and there was only a trace of nitrate in the soil which could be leached out, but the increased soil moisture stimulated nitrification. This may be explained also by the fact that oxygen in solution was carried in the soil by the heavy rains, giving the nitrifying bacteria more than they ordinarily obtained. By the end of March the nitrates of the virgin soil have again reached the zero level and do not rise from that for the rest of the year. The last downward curve in March corresponds to that of the other plots growing maize. There is no doubt that the decrease of the small amount of nitric nitrogen on the virgin grass-land in December, and the very low amount during January, can be attributed to

the veld grasses, which grew rapidly after the spring rains, and had nearly all matured by the end of January. After that time the nitrates rose again, but the writer makes no attempt to explain the subsequent fall in March. Lyon and Bizzell have shown that timothy, and also mixed grasses, like *phleum pratense*, *agrostis alba*, and *poa pratensis*, have a depressing effect on nitrification in the soil both at the time of growth and subsequently (27, 29, 31). The writer's records for the year show that the virgin soils with mixed native grasses and the soil growing teff also were lowest in nitrates.

### *June nitrate content, 1919 and 1920*

The final nitrate content of none of the five plots was so high in June, 1920, as it was in June, 1919. This may be accounted for by the fact that April of 1920 was very dry, whereas there was a good rainfall of 1.14 inches in April, 1919, when the growing season was over, and the temperature was still fairly high, hence there was increased nitrification. Neither was there subsequent rain to leach out the nitrates. It is true there was 0.6 inch of rain in May, 1920, and only a trace in May, 1919, but a week after the rain had fallen the temperature dropped rapidly and there were killing frosts, while after the rain in April, 1919, there were several weeks of much warmer weather. Attention has already been drawn to the upward tendency of the nitrates after these frosts, but the cold and dry soil was sufficient to prevent the nitrates amounting to what they did in 1919.

It is worthy of note that the moisture curve from the uncultivated fallow, which had developed a hard superficial crust, ended the season as high as that of the cultivated fallow, and higher than any other plots.

### *Soil temperature*

In figure 4 will be found plotted the soil-temperature curves, the average temperature for all the plots for the day being taken. It will be noticed that the soil temperature with one exception lies between the mean air temperature and the mean maximum air temperature. Lyon and Bizzell's (28) maximum soil-temperature curves practically correspond to the mean-air temperature curves. The writer's figures do not represent maximum temperatures, but are the temperatures taken at 6 inches at the time the sample was obtained and will be close to the maximum temperatures as they were procured between 10 a.m. and 3 p.m. The difference in temperature recorded on the same day is due chiefly to difference in time between the samples. The samples were always all taken on the same day, but not always in the same order.

### *Comparisons on seasonal variation*

If the curves in figure 1 are compared with those of Russell and Appleyard (38), it will be noticed that they show both steeper rises and falls, especially in December and January, corresponding to June and July in the northern

hemisphere. There is also a rise in March and April corresponding to the rise at Rothamsted in September and October, but whereas all the curves show a drop in December, the majority of the writers show a distinct rise in June, the corresponding winter months here. December in the north is cold and wet, whereas June here is cold and dry. The rainfall curves throughout the year show a much more even distribution at Rothamsted than at Potchefstroom, but our rains come during the warm and growing season and so there ought to be maximum nitrification at that time. Our plots corresponding to their unmanured ones rise much higher, some of them four or five times as high, but also fall lower in nitrate content. The nitrates here are produced more quickly; their highest figure in unmanured land is 17 parts per million, ours is 49 parts per million on cultivated fallow, and 55 parts per million on land that had carried cowpeas. Nitrification under these conditions seems

TABLE 5

*Soil temperatures at the time of sampling, 1919–20*

| PLOT AND RANGE | DECEMBER 9 | JANUARY 9 | FEBRUARY 4 | FEBRUARY 28 | MARCH 4 | MARCH 17 | APRIL 8 | MAY 6 | JUNE 8 |
|---|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. |
| Teff (A) | 27.0 | | 24 | 24.5 | 21.5 | | | 17.5 | 12.2 |
| Cowpeas harvested (B) | 26.5 | 25.0 | | 24.2 | 21.0 | 22.0 | 20.0 | 18.0 | 10.8 |
| Cowpeas plowed under (B) | | 26.0 | | 24.0 | 21.3 | 22.0 | 20.4 | 17.0 | 11.1 |
| Cultivated fallow | 28.0 | 25.0 | | 25.2 | 21.0 | 22.4 | 21.0 | 18.0 | 12.7 |
| Virgin soil | 28.0 | | | 23.4 | 21.8 | | 20.0 | 16.5 | 10.0 |
| Uncultivated fallow | | | | | | | 23.6 | 17.5 | |
| Maize after maize (C) | | | 24 | 24.3 | 23.5 | | | 18.0 | 11.0 |
| Teff after maize (D) | | | 24 | 25.5 | 23.0 | | 24.0 | 18.0 | 11.5 |
| Cowpeas plowed under after teff (A) | | | | 26.0 | 21.3 | | 21.3 | 16.5 | 11.5 |

more limited by moisture, the nitrate curve is not so even, but when moisture is adequate, nitrification is more efficient. On heavily dunged land Russell reports 37 parts per million of nitrate, but rarely above 23 parts per million. Tulaikoff on fallow land in a semiarid portion of Russia, as a 5-year average, did not find more than 22 parts per million in July (46). This approximates more closely the Rothamsted figures than the writer's.

Buckman in Montana shows an April and May crest corresponding to our October and November rises, and high crests in September and October corresponding to our March and April rise (5). He records nitrates reaching the maximum in October, whereas here the maximum was reached in December, corresponding to June there. He records amounts of 66 parts per million of nitric nitrogen. Lyon and Bizzell (28) show under humid conditions at Ithaca, N. Y., a very steep rise to 190 parts per million for bare unfertilized

soil and then a big drop again but not nearly as steep as that which the writer has here recorded. This maximum in July would correspond to ours in January, when our maximum was actually in December a month earlier.

Their work in general shows much higher quantities of nitric nitrogen in the field than the writer obtained even by incubating untreated South African soils under ideal conditions.

The amounts in general which the writer has recorded are higher than those of Stewart in Utah, and similar to Australian results, obtained by Scott and Robertson (36). Green, under Leipzig conditions (10), found a rise of nitrates from August to October, a fall to November, and then a marked rise in December, which he attributes to the mild winter of 1912–13. The latter corresponds to our June rise. The highest amount of nitric nitrogen which he records is 100 parts per million, but this is after incubation.

Compared with nitrification in Rothamsted soils the writer can endorse Watt's opinion that it is more active in Transvaal soils, but when compared with the much larger amounts found at the Cornell Experiment Station under humid conditions, the writer realizes that the above view cannot be applied to humid soils in general, as was done by Watt.

From the work here recorded it would seem that nitrification was much more active for a part of the year at least than at Rothamsted in the corresponding time, but that it was much inferior to nitrification at Ithaca, N. Y., as recorded by field samples.

### III. A STUDY OF THE NITRIFYING POWERS OF TWO SOILS

This study was carried out with the object of ascertaining whether, as was supposed, the nitrifying power of a soil that had been cultivated and irrigated for 14 years, was better than that of the same soil type a few hundred yards away that had never been irrigated or cultivated in that period. The virgin soil type is on a slope above the irrigation furrow and about 50 yards from it. The irrigated soil has grown wheat, oats, barley, maize, kaffir corn, mangels, lucerne, cowpeas and beans.

Samples of both soils were carefully taken to the depth of 1 foot, more soil being sieved and mixed than was required to fill two series of 20 half kerosene[1] tins each holding 18 pounds of dry soil.

The different amounts of lime and blood meal were mixed as per tables 6 and 7 after the soil had become quite air-dry. The weighed mixtures were rolled together on sheets of clean paper and put into their respective tins.

On July 1, 1919, all the 40 tins were watered at the rate of 15 per cent of the dry weight of the soil. All the tins were subsequently watered with equal amounts, the intervals depending largely on the rate of evaporation. The

[1] Kerosene, or paraffin as it is called in South Africa, is shipped in 4½-gallon tins. Petrol, or gasoline, comes in the same manner. These tins are used for plants, buckets and roofing material by many of the natives. The uses these tins are put to are innumerable.

TABLE 6

*Nitric nitrogen in a non-irrigated virgin soil*

| NUMBER | JULY 29, 29TH DAY | OCTOBER 20, 112TH DAY | JANUARY 5, 189TH DAY | MARCH 12, 256TH DAY | TREATMENT |
|---|---|---|---|---|---|
| | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | |
| 1 | 3.4 s | 12.3 s | 27.1 s | 47.1 s | Control |
| 2 | 7.7 g | 21.7 g | 36.1 g | 51.0 g | Limestone, 10 gm. |
| 3 | 5.1 s | 24.5 s | 31.9 s | 56.4 s | Limestone, 10 gm. |
| 4 | 10.9 g | 46.0 g | 65.5 g | 75.9 g | Limestone, 30 gm. |
| 5 | 9.7 s | 51.6 s | 82.8 s | 104.3 s | Limestone, 30 gm. |
| 6 | 5.2 g | 22.6 g | 33.8 g | 45.1 g | Control |
| 7 | 6.0 g | 38.6 g | 56.2 g | 55.1 g | Dried blood, 2 gm. |
| 8 | 3.8 s | 52.2 s | 44.8 s | 58.5 s | Dried blood, 2 gm. |
| 9 | 6.8 s | 24.3 s | 75.2 s | 79.3 s | Dried blood, 4 gm. |
| 10 | 5.8 g | 40.0 g | 76.7 g | 76.4 g | Dried blood, 4 gm. |
| 11 | 4.4 s | 29.0 s | 64.4 s | 83.6 s | Dried blood, 2 gm.; limestone, 10 gm. |
| 12 | 8.2 g | 25.8 g | 42.3 g | 47.4 g | Dried blood, 2 gm.; limestone, 10 gm. |
| 13 | 12.0 s | 82.6 s | 64.0 s | 96.4 s | Dried blood, 2 gm.; limestone, 30 gm. |
| 14 | 10.3 g | 61.1 g | 54.9 g | 83.0 g | Dried blood, 2 gm.; limestone, 30 gm. |
| 15 | 5.4 s | 30.9 s | 43.1 s | 51.9 s | Control |
| 16 | 4.3 g | 54.7 g | 46.3 g | 55.4 g | Dried blood, 2 gm.; limestone, 10 gm. |
| 17 | 6.6 s | 66.9 s | 54.9 s | 52.4 s | Dried blood, 2 gm.; limestone, 10 gm. |
| 18 | 7.7 g | 33.4 g | 51.3 g | 55.0 g | Dried blood, 2 gm.; limestone, 30 gm. |
| 19 | 6.0 s | 74.9 s | 63.5 s | | Dried blood, 2 gm.; limestone, 30 gm. |
| 20 | 4.0 g | 17.2 g | 33.1 g | 50.3 g | Control |

s—Signifies tin was on wooden stand.
g—Signifies tin was on dry ground below stand.

TABLE 7

*Nitric nitrogen in an irrigated and cultivated soil*

| NUMBER | JULY 29, 29TH DAY | OCTOBER 20, 112TH DAY | JANUARY 5, 189TH DAY | MARCH 12, 265TH DAY | TREATMENT |
|---|---|---|---|---|---|
| | *p.p.m.* | *p.p.m.* | *p p.m.* | *p.p.m.* | |
| 21 | 3.2 g | 5.9 g | 13.6 g | 13.8 g | Control |
| 22 | 3.3 s | 10.3 s | 18.0 s | 19.2 s | Limestone, 10 gm. |
| 23 | 3.6 g | 7.3 g | 12.8 g | 14.2 g | Limestone, 10 gm. |
| 24 | 3.8 s | 13.5 s | 21.3 s | 24.7 s | Limestone, 30 gm. |
| 25 | 4.5 g | 12.7 g | 21.5 g | 38.0 g | Limestone, 30 gm. |
| 26 | 3.5 s | 11.7 s | 13.7 s | 20.4 s | Control |
| 27 | 9.7 s | 24.1 s | 27.4 s | 39.1 s | Dried blood, 2 gm. |
| 28 | 7.4 g | 19.2 g | 31.4 g | 38.2 g | Dried blood, 2 gm. |
| 29 | 16.5 g | 42.3 g | 32.4 g | 59.4 g | Dried blood, 4 gm. |
| 30 | 19.2 s | 131.4 s | 46.6 s | 64.8 s | Dried blood, 4 gm. |
| 31 | 14.9 g | 32.0 g | 37.4 g | 40.2 g | Dried blood, 2 gm.; limestone, 10 gm. |
| 32 | 11.0 s | 28.3 s | 35.4 s | 51.7 s | Dried blood, 2 gm.; limestone, 10 gm. |
| 33 | 13.2 g | 21.6 g | 27.2 g | 24.8 g | Dried blood, 2 gm.; limestone, 30 gm. |
| 34 | 9.0 s | 28.2 s | 37.1 s | 60.6 s | Dried blood, 2 gm.; limestone, 30 gm. |
| 35 | 4.0 g | 9.1 g | 12.8 g | 21.1 g | Control |
| 36 | 11.3 s | 25.4 s | 38.8 s | 86.1 s | Dried blood, 2 gm.; limestone, 10 gm. |
| 37 | 11.2 g | 42.4 g | 29.4 g | 37.9 g | Dried blood, 2 gm.; limestone, 10 gm. |
| 38 | 10.6 s | 33.1 s | 40.7 s | 46.8 s | Dried blood, 2 gm.; limestone, 30 gm. |
| 39 | 13.4 g | 24.6 g | 26.0 g | 97.8 g | Dried blood, 2 gm.; limestone, 30 gm. |
| 40 | 2.2 s | 9.8 s | 18.2 s | 26.7 s | Control |

s—Signifies tin was on wooden stand.
g—Signifies tin was on dry ground below stand.

tins were exposed all the time to all temperatures and weather conditions, except that they were protected from rain by a galvanized iron roof. The wooden stands were not sufficient to accommodate all the tins, so about half of them had to be placed on the dry earth below. Samples of cultivated and virgin soil were placed alternately, two duplicates not being in the same locality, e.g., if one check were on the ground the other would be on the stand. An effort was made in this manner to remedy local advantages, such as those of temperature. That the differences between the soil temperature on the stand and in the tins on the ground was very marked, is well shown in table

TABLE 8

*Soil temperatures in tins on stand and on the ground*

| TIME | TIME ON STAND | TINS ON GROUND |
|---|---|---|
| *a.m.* | °C. | °C. |
| 7.00 | 9.7 | 12.0 |
| 7.30 | 12.0 | 12.6 |
| 8.00 | 16.0 | 14.7 |
| 8.30 | 18.5 | 16.5 |
| 9.00 | 24.5 | 19.3 |
| 9.30 | 29.9 | 20.0 |
| 10.00 | 33.4 | 21.0 |
| 10.30 | 33.7 | 22.3 |
| 11.00 | 35.9 | 23.5 |
| 11.30 | 35.8 | 24.1 |
| 12.00 | 35.5 | 25.0 |
| *p.m.* | | |
| 12.30 | 35.0 | 25.8 |
| 1.00 | 34.5 | 26.5 |
| 1.30 | 34.0 | 27.6 |
| 2.00 | 33.7 | 27.6 |
| 2.30 | 33.5 | 28.0 |
| 3.00 | 33.0 | 28.3 |
| 3.30 | 32.8 | 28.1 |
| 4.00 | 32.1 | 27.9 |
| 4.30 | 31.5 | 27.5 |
| 5.00 | 31.0 | 27.2 |

7, which is a comparative record of the soil temperatures during one day taken at half-hourly periods from 7 a.m. to 5 p.m. In the case of two tins of similar treatment, the one on the stand usually had a higher nitrate content on account of the more favorable temperature.

### *The nature of the soils*

Both soils were sandy loams in type but the virgin soil is lighter and more reddish in color than the cultivated soil, which is brown. The virgin soil lost on ignition 5.5 per cent, the cultivated 4.6 per cent. The virgin soil by the Veitch method showed a lime requirement of 1800 pounds per acre,

whereas the cultivated soil was slightly alkaline in reaction, although no free carbonate could be detected. This soil had probably originally a lime requirement the same as the virgin, but it has been irrigated for 14 years with a water of high lime content, and has been made slightly alkaline.

In tins no. 11, 12, 13, 14, 31, 32, 33 and 34, the limestone and blood meal were applied and mixed separately with the soil. In no. 16, 17, 18, 19, 36, 37, 38 and 39, the limestone and blood-meal were mixed together intimately for several hours before being applied and mixed with the soil.

It is a saving in labor to the farmer if he can mix together two substances before they are applied to the land, instead of applying them separately. Dry blood-meal and dry carbonate of lime should not react harmfully if mixed together for only a short time before application, and the writer was of the opinion that apart from saving labor, the practice might bring about more efficient nitrification. The above mixing was done to give some definite confirmation of this opinion if possible.

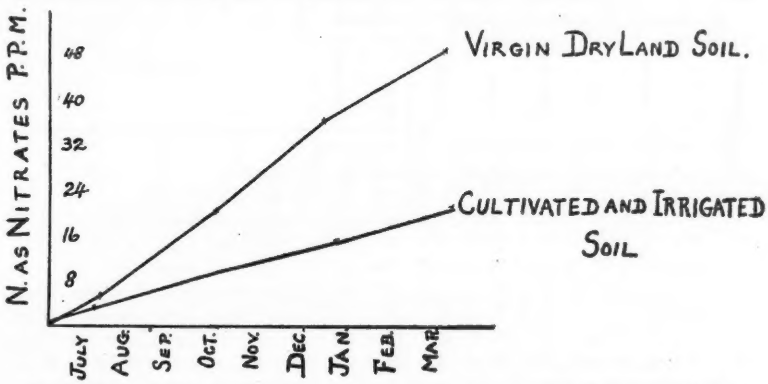


FIG. 7. NITRATE CURVE PLOTTED ON AVERAGE RESULTS OF THE UNTREATED SOILS

*The influence of our winter temperature on nitrification*

The temperature for the most part of the first period to July 29 was low at night, usually below 36°F., but did not drop to freezing. The maximum day shade temperatures, on the other hand, were in the vicinity of 72°F. At the beginning of the experiment there was no trace of nitrates in the virgin soil, while the cultivated contained only 0.5 part per million. At the end of 29 days there was a considerable increase in nitric nitrogen in both soils, and by referring to figure 7, it will be seen that the virgin and cultivated controls show a steady rise through July, August, September and October, the months during which there was very little activity in the field plots, as shown in figure 1. It would seem from these facts that it is moisture and not temperature that is the chief limiting factor for nitrification during the cold dry months in the Transvaal.

### *General discussion of results*

In the first period the virgin soil is slightly ahead of the cultivated, as regards untreated soil, and also where lime has been applied. In that first period of 29 days the cultivated soil has shown superior powers of nitrification wherever blood-meal has been applied. The lime requirements of the two soils were so different that it would be expected that the virgin soil would give much better results from its application.

During the next three months the temperature has steadily increased and so have the nitrates, both in the controls and in the treated tins. The nitrates in the virgin soil are now almost without exception well ahead of those in the cultivated soil, and they maintain their superior lead through the 8½ months that the experiment was continued.

TABLE 9

*Data of tables 6 and 7 in condensed form*

| NUMBER | JULY 29 | | OCTOBER 20 | | JANUARY 5 | | MARCH 12 | | TREATMENT |
|---|---|---|---|---|---|---|---|---|---|
| | Virgin | Cultivated | Virgin | Cultivated | Virgin | Cultivated | Virgin | Cultivated | |
| | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | |
| 1 | 4.5 | 3.2 | 20.7 | 9.1 | 34.2 | 14.5 | 48.6 | 20.5 | Control |
| 2 | 6.4 | 3.4 | 23.1 | 8.8 | 34.0 | 15.4 | 53.7 | 16.6 | Limestone, 10 gm. |
| 3 | 10.3 | 4.1 | 53.8 | 13.1 | 74.1 | 21.4 | 89.1 | 31.3 | Limestone, 30 gm. |
| 4 | 4.9 | 8.5 | 45.4 | 21.6 | 50.5 | 29.4 | 56.8 | 38.6 | Dried blood, 2 gm. |
| 5 | 6.3 | 17.3 | 32.1 | 86.8 | 75.9 | 39.5 | 77.8 | 62.1 | Dried blood, 4 gm. |
| 6 | 6.3 | 12.9 | 27.3 | 30.1 | 53.3 | 36.4 | 65.5 | 46.0 | Dried blood, 2 gm.; limestone, 10 gm. |
| 7 | 11.2 | 11.1 | 71.8 | 24.9 | 59.4 | 32.1 | 89.2 | 42.7 | Dried blood, 2 gm.; limestone, 30 gm. |
| 8 | 5.4 | 11.2 | 60.8 | 33.9 | 50.6 | 34.1 | 53.9 | 62.0 | Dried blood, 2 gm.; limestone, 10 gm. |
| 9 | 6.8 | 12.0 | 54.1 | 28.8 | 57.4 | 33.3 | *55.0 | 72.3 | Dried blood, 2 gm.; limestone, 30 gm. |

* Determination from only one tin, accident to the other.

The maximum amount of nitric nitrogen obtained in the virgin controls corresponds closely to the maximum obtained in the fallow land of the same soil type in the field. In the tins this amount of nitric nitrogen, 48 parts per million, was reached by a steady upward curve in a period of 8½ months terminating in March, 1920.

The cultivated fallow in the field increased 24 parts per million in 4 weeks after the rain, and attained its maximum of 49 parts per million at the end of December, 1919. In the middle of March, 1920, it was down to 4.5 parts per million. The maximum under field conditions seems to be reached much more quickly. This may be due to partial sterilization by the hot sun on a dry soil. Of course, during the greater part of the day the tins were in the shade, and such high soil temperatures as those obtaining in the field would not prevail generally.

In order to appreciate better the differences shown in tables 6 and 7, these data have been condensed and recorded in abbreviated form in table 9. The figures represent the averages of two tins each, and of four controls. The data are represented graphically in figure 8.

In no. 6 and 7, dried blood and limestone were applied separately. In no. 8 and 9 dried blood and limestone were mixed together before application.

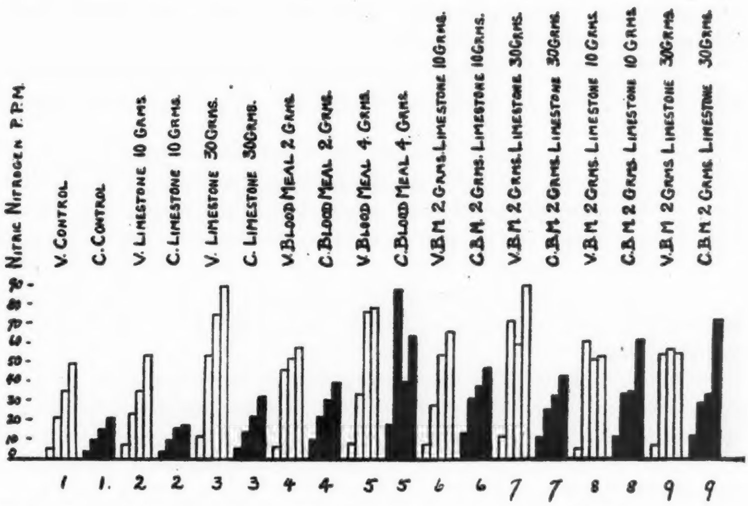


Fig. 8. Graphic Summary of the Experiment on the Influence of Temperature on Nitrification

Unshaded graphs represent the virgin soil; shaded, the cultivated soil

*A discussion of table 9 and figure 8*

Both figures 7 and 8 show that in general nitrification was better in the soil from the non-irrigated virgin land than in that from the irrigated and cultivated land. This depression of nitrification by cultivation and irrigation was contrary to what the writer had expected to find.

Since his experiment has been completed, the writer finds that McBeth and Smith in Utah (13) also conclude that the application of irrigation water reduced the nitrifying powers of the soils as determined by laboratory methods.

On the virgin soil better results were obtained from blood-meal and limestone when applied separately than when mixed together before application. On the irrigated and cultivated soil on two occasions better results were obtained by mixing the blood-meal and limestone; on two others this was not the case, but the final determinations of nitrates in no. 8 and 9 are well ahead of those in no. 6 and 7.

It would seem from the data here obtained that the practice of mixing blood meal and limestone together before applying to the land cannot be recommended because of its uniform beneficial effects on nitrification, although it may be as a means of saving labor.

Limestone alone at the rate of 10 gm. per tin, or 3057 pounds per acre, does not appear to have benefited nitrification in either the virgin or the cultivated soil, but when three times that amount is applied, nitrification is greatly increased over the controls, about three-fourths more on the virgin and nearly as much on the cultivated soil.

The cultivated soil is alkaline to start with and the virgin has a lime requirement of 1800 pounds per acre. It is strange that they benefit about equally from heavy liming.

Two grams of blood meal with the virgin soil did not produce as much nitrate as 30 gm. of limestone. In the cultivated soil, on the other hand, 2 gm. of blood meal produced more nitrate than 30 gm. of limestone. Even 4 gm. of blood meal (1200 pounds per acre) in the virgin soil did not produce as much nitrate as 30 gm. of limestone, whereas in the cultivated soil more than twice as much was produced. These amounts are far above the limits that would be used in practice in South Africa, but still the results from them are illuminating.

The addition of 10 gm. of limestone to the soil containing 2 gm. of blood meal gave slightly increased amounts of nitric nitrogen with both soils, whereas the addition of 30 gm. in tins containing 2 gm. of blood meal greatly increased nitrification in the virgin soil, but appears to have depressed it somewhat in the cultivated soil.

From the data obtained in this experiment the following conclusions seem possible:

1. The outdoor winter temperatures of July and August, 1919, were not sufficient to stop nitrification, while the soil moisture was adequate.
2. It seems as if nitrification is kept in check in our cold dry winters more by lack of moisture than by actual cold.
3. Nitrates accumulated in the winter and increased for 8½ months continuously, because the soil was protected from leaching losses by rain.
4. In some cases there seems to be a benefit shown by increased nitrification in addition to a saving of labor when blood meal and limestone are mixed together before being applied to the soil.
5. Cultivation and irrigation for 14 years seemingly depressed the nitrifying power of the soil studied.
6. Limestone applied in amounts largely in excess of those used in practice greatly stimulates nitrification, even in a slightly alkaline soil. This does not imply, however, that superior crop yields could be expected from such an application, for in common with most South African soils, the crop yields would probably be limited by lack of phosphates. Such applications, although largely stimulating nitrification, under our conditions would mean a monetary loss.

## IV. THE NITRIFICATION OF COWPEAS USED AS A GREEN MANURE

Toward the end of January, 1920, on the cultivated and irrigated land from which soil had been taken for the last study, but on another portion of the field, 24 $\frac{1}{1000}$-acre plots were prepared. The soil in this section is a brown sandy loam, with 5.9 per cent of organic matter, and 0.1 per cent of nitrogen. Whereas on the last study dried blood was used to ascertain the soil's nitrifying power, in this case cowpeas were taken. It is the policy of this station

TABLE 10

*Nitrification of cowpeas with various amounts of lime*

| NUMBER | FEBRUARY 11 | | | | MARCH 1 | | APRIL 14 | | MAY 20 | | JUNE 22 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $NH_3$ | Nitrites | Nitrates | Soil moisture | Nitrates | Soil moisture | Nitrates | Soil moisture | Nitrates | Soil moisture | Nitrates | Soil moisture |
| | *p.p.m.* | *p.p.m.* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* |
| 1 | 0.3 | Nil | 2.6 | 14.5 | 1.4 | 14.5 | 6.3 | 11.4 | 5.2 | 11.3 | 5.9 | 11.2 |
| 2 | 0.7 | Nil | 5.4 | 15.1 | 6.8 | 14.8 | 6.3 | 11.2 | 8.8 | 11.3 | 8.1 | 10.7 |
| 3 | 1.0 | Nil | 8.9 | 14.5 | 12.5 | 14.0 | 11.6 | 10.9 | 18.2 | 12.1 | 10.3 | 10.1 |
| 4 | 1.8 | Nil | 6.3 | 14.2 | 9.4 | 14.3 | 8.1 | 11.5 | 14.3 | 10.9 | 11.1 | 10.2 |
| 5 | 0.8 | Nil | 8.6 | 13.4 | 7.1 | 13.7 | 5.9 | 10.4 | 13.6 | 10.5 | 14.3 | 10.5 |
| 6 | 0.9 | Nil | 7.0 | 13.8 | 9.0 | 13.4 | 8.6 | 11.6 | 20.7 | 10.3 | 11.4 | 10.3 |
| 7 | 0.9 | Nil | 9.1 | 13.8 | 10.0 | 13.3 | 5.7 | 10.5 | 14.1 | 11.0 | 12.3 | 9.5 |
| 8 | 0.7 | Nil | 8.5 | 14.1 | 5.5 | 14.3 | 9.1 | 10.7 | 12.1 | 10.7 | 12.4 | 9.6 |
| 9 | 0.5 | Nil | 4.7 | 12.9 | 1.4 | 14.4 | 7.8 | 12.0 | 11.6 | 11.6 | 8.5 | 10.1 |
| 10 | 1.3 | Nil | 7.0 | 13.5 | 5.5 | 14.6 | 7.5 | 12.3 | 10.9 | 10.7 | 6.2 | 9.4 |
| 11 | 1.4 | Nil | 2.6 | 13.1 | 4.3 | 14.7 | 4.2 | 11.1 | 9.3 | 10.9 | 8.3 | 9.9 |
| 12 | 0.8 | Nil | 4.0 | 15.4 | 5.3 | 14.8 | 9.2 | 11.6 | 13.7 | 11.4 | 10.8 | 9.8 |
| 13 | 2.7 | Nil | 6.2 | 13.2 | 7.2 | 16.1 | 11.5 | 11.0 | 10.1 | 10.9 | 10.3 | 10.0 |
| 14 | 2.5 | Nil | 2.5 | 13.5 | 5.7 | 14.9 | 6.4 | 11.8 | 10.3 | 11.7 | 10.0 | 9.2 |
| 15 | 1.3 | Nil | 4.4 | 12.1 | 5.3 | 14.2 | 8.6 | 11.6 | 9.5 | 11.4 | 14.1 | 8.1 |
| 16 | 2.4 | Nil | 3.5 | 12.0 | 4.4 | 14.2 | 6.4 | 11.7 | 13.1 | 11.4 | 9.6 | 10.5 |
| 17 | 1.1 | 0.1 | 5.7 | 13.4 | 4.7 | 15.4 | 9.0 | 12.3 | 11.5 | 11.9 | 11.4 | 10.7 |
| 18 | 2.1 | Nil | 3.6 | 11.8 | 4.1 | 15.6 | 5.8 | 12.8 | 6.6 | 12.2 | 9.4 | 10.6 |
| 19 | 2.3 | Trace | 2.9 | 14.6 | 5.2 | 15.7 | 8.6 | 12.4 | 12.7 | 12.2 | 12.4 | 10.7 |
| 20 | 2.2 | Trace | 4.9 | 14.0 | 7.6 | 13.7 | 7.2 | 11.6 | 17.8 | 11.0 | 15.0 | 10.2 |
| 21 | Trace | Nil | 4.9 | 14.4 | 5.8 | 15.0 | 8.7 | 12.6 | 10.2 | 10.8 | 10.5 | 10.7 |
| 22 | Trace | Trace | 3.5 | 14.3 | 5.7 | 14.8 | 7.1 | 12.4 | 14.9 | 11.7 | 16.1 | 9.5 |
| 23 | Trace | Nil | 3.8 | 13.5 | 5.1 | 14.6 | 7.0 | 12.3 | 11.5 | 11.4 | 14.6 | 8.4 |
| 24 | Trace | Trace | 4.3 | 13.9 | 6.3 | 14.7 | 10.0 | 12.0 | 11.5 | 11.3 | 11.3 | 9.9 |

to advocate the use of green manuring in preference to all other nitrogenous fertilizers, and it was felt that some observations in this area on the decomposition of our peas, and the amount of nitrate formed under field conditions might be of value.

An endeavor also was made to ascertain whether ground limestone or slaked lime was the better in bringing about decomposition and nitrate formation, and what quantities of these limes it was best to use.

Just as in the last study an attempt was made to find out if mixing lime and blood meal together gave increased nitrification in addition to saving

labor, so here the mixing of cowpeas and lime was tried. Lime was applied to the soil and turned under, then the green-cut cowpeas, just beginning to form pods, were applied and turned under. This treatment was compared

TABLE 11

*Treatment and temperature of $\frac{1}{1000}$-acre plots*

| NUMBER | TREATMENT PER ACRE | APRIL 14 | | MAY 20 | | JUNE 22 | |
|---|---|---|---|---|---|---|---|
| | | °C. | Time | °C. | Time | °C. | Time |
| 1 | Control | 17.0 | 9:35 | 14.0 | 9:20 | 10.0 | 9:15 |
| 2 | 2 tons cowpeas | 18.0 | 9:55 | 14.0 | 9:30 | 10.5 | 9:30 |
| 3 | 2 tons cowpeas; 2000 lbs. $CaCO_3$ applied before cowpeas | 19.0 | 10:20 | 14.0 | 9:42 | 10.0 | 9:40 |
| 4 | 2 tons cowpeas; 2000 lbs. $CaCO_3$ mixed with cowpeas | 19.0 | 10:40 | 14.0 | 10:05 | 10.0 | 9:50 |
| 5 | 2 tons cowpeas; 1000 lbs. $CaCO_3$ applied before cowpeas | 19.0 | 11:00 | 14.5 | 10:45 | 11.0 | 10:05 |
| 6 | 2 tons cowpeas; 1000 lbs. $CaCO_3$ mixed with cowpeas | 19.0 | 11:15 | 14.5 | 10:55 | 10.5 | 10:15 |
| 7 | 2 tons cowpeas; 500 lbs. $CaCO_3$ applied before cowpeas | 19.0 | 11:30 | 14.7 | 11:05 | 11.0 | 10:25 |
| 8 | 2 tons cowpeas; 500 lbs. $CaCO_3$ mixed with cowpeas | 19.3 | 11:45 | 15.0 | 11:15 | 11.0 | 10:35 |
| 9 | 2 tons cowpeas; 2000 lbs. $Ca(OH)_2$ applied before cowpeas | 19.3 | 12:50 | 15.5 | 11:35 | 11.0 | 10:45 |
| 10 | 2 tons cowpeas; 2000 lbs. $Ca(OH)_2$ mixed with cwpeas. | 20.8 | 2:05 | 15.5 | 11:45 | | |
| 11 | Control | 20.8 | 2:17 | 16.0 | 12:00 | | |
| 12 | 2 tons cowpeas; 500 lbs. $Ca(OH)_2$ applied before cowpeas | 20.0 | 2:30 | 16.0 | 12:05 | | |
| 13 | 2 tons cowpeas; 500 lbs. $Ca(OH)_2$ applied before cowpeas | 20.0 | 3:00 | 17.0 | 2:15 | | |
| 14 | 2000 lbs. $CaCO_3$ | 21.0 | 3:08 | 17.0 | 2:18 | | |
| 15 | 1000 lbs. $CaCO_3$ | 20.8 | 3:30 | 17.5 | 2:30 | | |
| 16 | 500 lbs. $CaCO_3$ | 21.0 | 3:40 | 17.5 | 2:45 | | |
| 17 | 2000 lbs. $Ca(OH)_2$ | 21.0 | 3:50 | 17.5 | 3:00 | 12.6 | 2.10 |
| 18 | 500 lbs. $Ca(OH)_2$ | 20.5 | 2:05 | 17.5 | 3:15 | 13.0 | 2:20 |
| 19 | 2000 lbs. $Ca.CO_3$ | 18.0 | *9:25 | 17.5 | 3:25 | 13.5 | 2:30 |
| 20 | 1000 lbs. $Ca.CO_3$ | 18.5 | 9:40 | 18.0 | 3:40 | 14.0 | 2:40 |
| 21 | 500 lbs. $Ca.CO_3$ | 19.0 | 10:00 | 17.5 | 3:45 | 12.5 | 2:50 |
| 22 | 2000 lbs. $Ca(OH)_2$ | 19.8 | 10:15 | 17.5 | 4:00 | 13.5 | 3:00 |
| 23 | 500 lbs. $Ca(OH)_2$ | 20.1 | 10:25 | 17.0 | 4:10 | 13.6 | 3:15 |
| 24 | 2 tons cowpeas | 20.4 | 10:41 | 17.0 | 4:15 | 13.0 | 3:25 |

* Samples and temperatures from here onward taken April 15.

with the process of applying cowpeas to the soil, sprinkling them with lime, and turning under the two together.

The detailed treatment of each plot is given in table 11, and table 10 contains the amounts of nitrate present on five different dates and the moisture content of the soil at those times.

On January 28, 1920, the green cowpeas were turned under on the $\frac{1}{1000}$-acre plots, and two weeks later on February 11 samples were taken for the first determinations. Two 1-foot-deep holes were made in each plot and the samples from the two mixed together. From the mixture a representative sample was taken. Determinations of ammonia, nitrites and nitrates on February 11 were made on every sample taken.

As only traces of nitrites were found and the quantity of ammonia was so small at the first sampling, no more of these determinations were made. It rained so heavily shortly after the cowpeas were turned under, and at so many other times during the two weeks previous to the first sampling, that the cowpeas were completely decomposed, only occasional traces of the fibre of the stem being found. It is unfortunate that a time should have been chosen, which has subsequently been shown in figure 1 to be the worst in the year for finding nitrates in the first foot of soil. There is no doubt from the depth samples taken in spots not far removed from these $\frac{1}{1000}$-acre plots, that the nitrates were carried down below the feeding zone of most roots. It was quite impracticable to take depth samples, as with pick and spade, the implements at the writer's disposal, nothing would have been left of a $\frac{1}{1000}$-acre plot after having been once sampled below the third foot.

It is possible that the data would have been more valuable, if the season had not been quite so wet. The same soil type under the protected conditions prevailing in the last study gave much higher results in nitric nitrogen.

In order to study the 5 months' data to better advantage, they have been condensed in table 12.

These data are given in graphic form in figure 9 which shows the amount of nitric nitrogen in parts per million in each plot for the five dates of sampling. The inset shows the soil temperature steadily decreasing throughout three months. If reference is made to figure 4, it will be seen that these soil temperatures for the dates plotted fall in between the mean air temperatures and soil temperatures of the dry-land plots. The difference in soil moisture between the two series of plots is sufficient to account for this difference in temperature. On June 22 the soil temperatures of the two series coincide and their soil-moisture contents also are very similar.

Two tons of green cowpea hay per acre did not increase the nitrate content much above that of the controls. The application of 1 ton of limestone before the cowpeas greatly increased nitrification over the first two mentioned plots and also gave better results than turning under the cowpeas and limestone together. With 1000 pounds of limestone, though, slightly better results were obtained by turning under the cowpeas and limestone together, than by applying them separately. With 500 pounds of limestone, the results are again lower, and turning under the cowpeas and limestone together has not increased the nitric nitrogen above that of the plot on which they were applied separately.

TABLE 12

*Average of duplicates in table 10*

| TREATMENT PER ACRE | NUMBER | FEBRUARY 11 | MARCH 1 | APRIL 14 | MAY 20 | JUNE 22 |
|---|---|---|---|---|---|---|
| | | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* |
| Control | 1 | 2.6 | 2.8 | 5.2 | 7.3 | 7.1 |
| 2 tons cowpeas | 2 | 4.8 | 6.5 | 8.0 | 10.0 | 9.7 |
| 2000 lbs. $CaCO_3$ applied before 2 tons cowpeas | 3 | 8.9 | 12.5 | 11.6 | 18.2 | 10.3 |
| 2000 lbs. $CaCO_3$ mixed with 2 tons cowpeas | 4 | 6.3 | 9.4 | 8.1 | 14.3 | 11.1 |
| 1000 lbs. $CaCO_3$ applied before 2 tons cowpeas | 5 | 8.6 | 7.1 | 5.9 | 13.6 | 14.3 |
| 1000 lbs. $CaCO_3$ mixed with 2 tons cowpeas | 6 | 7.0 | 9.0 | 8.6 | 20.7 | 11.4 |
| 500 lbs. $CaCO_3$ applied before 2 tons cowpeas | 7 | 9.1 | 10.0 | 5.7 | 14.1 | 12.3 |
| 500 lbs. $CaCO_3$ mixed with 2 tons cowpeas | 8 | 8.5 | 5.5 | 9.1 | 12.1 | 12.4 |
| 2000 lbs. $Ca(OH)_2$ applied before 2 tons cowpeas | 9 | 4.7 | 1.4 | 7.8 | 11.6 | 8.5 |
| 2000 lbs. $Ca(OH)_2$ mixed with 2 tons cowpeas | 10 | 7.0 | 5.5 | 7.5 | 10.9 | 6.2 |
| 500 lbs. $Ca(OH)_2$ applied before 2 tons cowpeas | 11 | 4.0 | 5.3 | 9.2 | 13.7 | 10.8 |
| 500 lbs. $Ca(OH)_2$ mixed with 2 tons cowpeas | 12 | 6.2 | 7.2 | 11.5 | 10.1 | 10.3 |
| 2000 lbs. $CaCO_3$ | 13 | 2.7 | 5.4 | 7.5 | 11.5 | 11.2 |
| 1000 lbs. $CaCO_3$ | 14 | 4.6 | 6.4 | 7.9 | 13.6 | 14.5 |
| 500 lbs. $CaCO_3$ | 15 | 4.2 | 5.1 | 7.5 | 11.6 | 10.0 |
| 2000 lbs. $Ca(OH)_2$ | 16 | 4.6 | 5.2 | 8.0 | 13.2 | 13.7 |
| 500 lbs. $Ca(OH)_2$ | 17 | 3.7 | 4.6 | 6.4 | 9.0 | 12.0 |

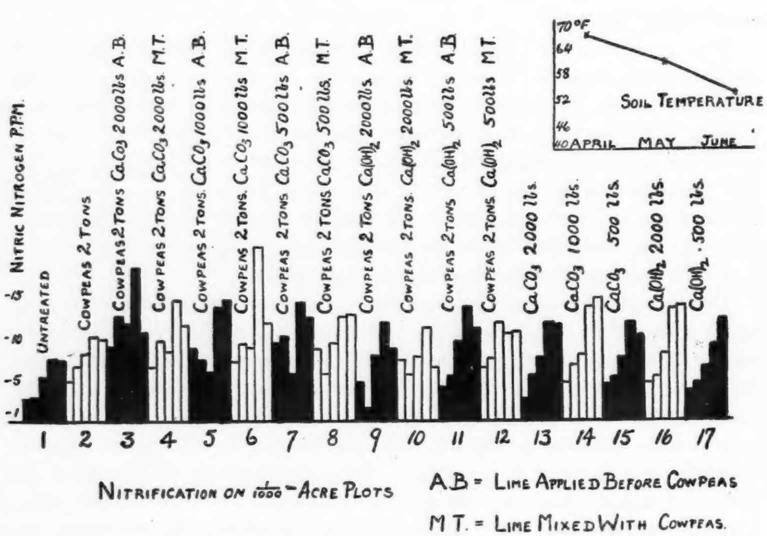


FIG. 9. AMOUNT OF NITRATE PRESENT ON FIVE DIFFERENT DATES FOR EACH TREATMENT

With regard to the manner of application the same holds true concerning 2000 pounds of slaked lime, which in addition seems to have depressed the nitrification, as lower results were obtained than with 500 pounds of limestone.

Five hundred pounds of slaked lime gave better results than 2000 pounds when applied with and before cowpeas, but here again no advantage seems to have been gained by mixing the two together.

When the ground limestone was applied alone the 1000-pound rate gave better results than the 2000 and 500-pound applications. The results were about equal for the application of 2000 pounds and 500 pounds of ground limestone.

When slaked lime at the rate of 2000 pounds was applied alone, bettter results were obtained than by applying it to the same plot as cowpeas. The results with 500 pounds of slaked lime alone, however, are about as good as with the 2000-pound application.

Slaked lime at the rate of 2000 pounds per acre has given slightly better results than the same amount of ground limestone, but with the 500-pound application the limestone is again a little better.

Taking the results throughout, the ground limestone has given somewhat better results than the slaked lime. The limestone at the rate of 1000 pounds per acre has given the best results.

Mixing the cowpeas and lime before turning them under has with the exception of no. 6 (fig. 4) given slightly worse results than when these substances were applied separately. But the slight difference in favor of the separate application would not, in the opinion of the writer, offset the labor saved in turning them under together.

### *Summary and conclusions for study*

From this study the following conclusions seem warranted.

1. Under these conditions of climate green cowpea hay, when turned under in a moist soil, decomposes within two weeks, especially if the operation has been followed by good rains.

This was in extreme contrast to the decomposition of the cowpea hay turned under on the dry-land plots the previous season. The soil was barely moist and no rain worth mentioning fell afterwards. After a prolonged drought of 5 months, traces of cowpeas could still be found in the soil. This shows how carefully the farmer in semi-arid regions must study the weather and soil, in order to get the maximum benefit from turning under green manure. For example, in the instance just mentioned better results were obtained where the cowpeas had been cut for hay, than where they had been turned under, on account of the slow decomposition in a dry soil, which is apt to become drier in the process.

2. Although excessive rains such as were experienced here in February bring about very quick and complete decomposition of the green manure, yet the small increase found in the nitrate subsequently, where the cowpeas

had been turned under, points to the fact that the valuable decomposition products were carried below the first foot of soil. This conclusion is by analogy from the nitrates found deep down on other parts of the farm after these rains.

It would seem that very heavy rains are not desirable on account of this washing down of the soluble products to the lower depths of the soil. Rainfall penetrating about 18 inches would be better, when only the storing of the products of decomposition is considered.

3. The results obtained with slaked lime and ground limestone on a soil slightly alkaline indicate that the ground limestone was the better. This gave the best results at the application of 1000 pounds per acre.

4. The turning in of green cowpea hay and either form of lime together, did not increase the amount of nitric nitrogen as was expected, except in one case. The writer still thinks, however, that the saving of labor will offset any small depression of nitrification which these results seem to indicate.

## V. EFFECT OF LIME ON NITRATE PRODUCTION IN NON-IRRIGATED LAND

On January 13, 1920, a virgin strip of land was plowed and cultivated, just beside the strip on which the virgin samples were taken all during the seasonal variation study. On January 15 these $\frac{1}{20}$-acre plots were limed and planted to potatoes at the rate of 1200 pounds per acre. The detailed amounts of the two forms of lime applied will be found in table 13.

### *The object of the experiment*

Many farmers have the idea that lime is necessary for growing potatoes, so the primary object was to obtain data to strengthen the opinion of this station on the matter. As far as the present investigation is concerned, it was an attempt to ascertain how different forms and amounts of lime affected nitrification in non-irrigated soil under field conditions. These seven plots are alongside the potato plots on which the nitrates were determined in the preliminary study. The soil on which the present studies were made is a brown sandy loam which shows a lime requirement of 580 pounds per acre by the Veitch method. It contains 0.06 per cent of nitrogen and has a loss on ignition of 6.3 per cent. At a depth of about 14 inches limonite gravel is found, under plots 1, 2 and 3, but the distance of this from the surface gradually increases and under no. 7 it is nearly 3 feet down.

Before this land was plowed it contained only traces of nitrates; on January 30, 17 days later, 40 part per million were found.

On February 6, when the first samples over all the seven plots were taken, the potatoes were just coming up. On February 24 they were 5 to 6 inches high. On March 4 the plots were cultivated, on the tenth they were ridged up and hand-hoed. By April 9 some were flowering.

The data in table 13 are presented graphically in figure 10.

TABLE 13

*Nitrates produced on non-irrigated land with lime*

Nitric nitrogen in parts per million, soil moisture in per cent

| TREATMENT PER ACRE | PLOT NUMBER | FEBRUARY 6 | | FEBRUARY 24 | | APRIL 9 | | MAY 18 | | JUNE 17 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture |
| 300 lbs. carbonate of lime..... | 1 | 10.5 | 12.3 | 3.6 | 15.0 | 10.5 | 9.8 | 5.5 | 12.0 | 7.4 | 10.0 |
| 150 lbs. carbonate of lime..... | 2 | 6.1 | 12.1 | 7.5 | 15.1 | 1.3 | 9.4 | 7.2 | 10.8 | 8.6 | 9.7 |
| 1000 lbs. carbonate of lime..... | 3 | 13.5 | 10.9 | 7.1 | 14.2 | 4.2 | 10.2 | 13.0 | 10.1 | 20.2 | 10.3 |
| 300 lbs. slaked lime........... | 4 | 19.2 | 12.1 | 1.4 | 14.3 | 1.7 | 10.3 | 8.0 | 10.3 | 7.1 | 9.6 |
| 150 lbs. slaked lime........... | 5 | 34.6 | 11.8 | 9.4 | 14.2 | 2.4 | 10.3 | 11.1 | 9.4 | 17.8 | 8.7 |
| 1000 lbs. slaked lime.......... | 6 | 22.5 | 11.5 | 5.3 | 13.3 | 11.5 | 9.9 | 10.0 | 9.0 | 22.3 | 8.7 |
| Control...................... | 7 | 16.0 | 11.4 | 9.8 | 13.7 | 20.7 | 11.7 | 23.0 | 11.1 | 15.3 | 11.0 |

TABLE 14

*Nitrates in second foot of plots listed in table 13, February 25, 1920*

| PLOT NUMBER | NITRIC NITROGEN IN SECOND FOOT | SOIL MOISTURE OF SECOND FOOT | SOIL TEMPERATURE OF PLOTS, JUNE 17 |
|---|---|---|---|
| | *p.p.m.* | *per cent* | °C. |
| 1 | 2.1 | 14.2 | 9.5 |
| 2 | Trace | 14.0 | 9.7 |
| 3 | 6.8 | 13.8 | 9.5 |
| 4 | 12.5 | 14.6 | 10.2 |
| 5 | 16.0 | 15.2 | 10.0 |
| 6 | 19.1 | 14.6 | 12.0 |
| 7 | 14.4 | 15.0 | 10.0 |

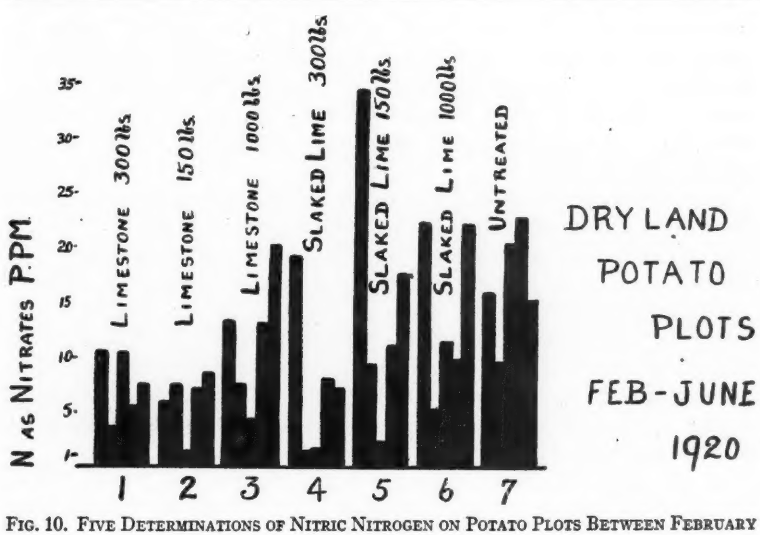


FIG. 10. FIVE DETERMINATIONS OF NITRIC NITROGEN ON POTATO PLOTS BETWEEN FEBRUARY 6 AND JUNE 17, 1920

*Discussion of results*

With the exception of one plot there was a great deal more nitrogen present in the surface foot of the soil on February 6 than there was on February 24. The rainfall chart (fig. 3) shows that there was over $5\frac{1}{2}$ inches of rain in one week, between those dates. On February 25 the writer obtained second-foot samples on these seven plots, and in four of these deeper samples there was considerably more nitrate than in the surface foot of the previous day.

Although plot 2 on February 24 does not show a drop below its February 6 content, yet its nitrate content on the former date is lower than that of plots 3, 5 and 7, all of which showed a distinct drop at that time.

After the experiment had been started it was found out that long ago a road had crossed this field in the vicinity of plots 1, 2 and 3. In spite of equal plowing and cultivating these three plots seemed to be more compact than the others, as was noticed particularly in taking samples. Plots 1, 2 and 3 are, therefore, probably lower in nitrate content all through on account of bad aeration.

The first four plots are undoubtedly the poorest but of them no. 3, receiving limestone at the rate of 1000 pounds per acre, is decidedly the best.

The high amount of nitric nitrogen in no. 5 on February 6 can hardly be attributed to slaked lime at the rate of 150 pounds per acre, when it is remembered that the check plot on January 30 contained 40 parts per million of nitric nitrogen, which is considerably more.

The untreated plot no. 7 maintains the best nitrate content, considered over the whole period of 5 months. It will also be noticed that it had the best moisture content on the last three determinations.

Comparing the limed plots with the untreated it cannot be found that the liming increased nitrification at all. However, it was noticed during the various samplings that the tilth of plots 5, 6 and 7 was better than that of the first three, and no. 7 appears to be best of all in tilth. This observation corresponds to the nitrate results obtained, and indicates that aeration is a much more important factor for nitrate production than lime, on a newly plowed soil only slightly acid.

Attention has already been drawn to the fact that gravel was found much closer to the surface under plots 1, 2 and 3 than under no. 6 and 7.

In no case is the final nitrate content in June below 7 parts per million. In two cases it is over 20 parts per million and in one over 17 parts per million.

If the nitrate content of the potato land in June, 1920, is compared with that of the teff, cowpea and maize land in the same month, it will be seen that only one of the five contains more than 5 parts per million of nitric nitrogen.

These data are in accordance with the June, 1919, observations recorded in table 1, which shows a much higher nitrate content for the potato plots than for the maize at that time. The actual amount of nitrate, around 5 parts per million, in the maize plots, is very similar for both 1919 and 1920. The amount of nitrate in the potato plots of 1919 is greater than in 1920,

but they were not the same plots for the two years, being located adjacent to each other. The 1919 plots had a better general tilth than the newly plowed and limed plots of the following year, but as the potatoes were dug only on June 28, 1920, these plots did not have the benefit of increased aeration as was the case in 1919.

Attention is again drawn to the rise in nitrates in June over the May amounts, with one exception, although the weather after May 18 became colder and colder, and there were killing frosts, while the soil became drier. The writer has already indicated that he believes this upward rise to be due to partial sterilization of the soil, due to the killing off of the enemies of the nitrifying bacteria by frost. This study seems to indicate the following conclusions.

### *Conclusions*

1. The lower amount of nitric nitrogen on February 24 than was found on the sixth of the month, was due to the very heavy rains between these dates, and the washing down of the nitrates below the first foot. This is quite in accordance with the data obtained at the time on the seasonal-variation plots, and in the depth-sampling study yet to be recorded.
2. The application of two kinds of lime in various amounts did not improve nitrification over the untreated soil.
3. Aeration on this newly cultivated and only slightly acid soil appears to be a much more important factor than lime.
4. The observations made in the 1919 preliminary studies are confirmed in that the potato plots ended up with much more nitric nitrogen than the maize.
5. The potato plots also had more nitric nitrogen in June, 1920, than the teff and cowpea plots in study II.
6. After the cold dry weather and killing frosts of the latter part of May and early June, there is a distinct rise in nitrates in six out of seven plots.

## VI. AMOUNTS OF NITRATES IN FIRST FIVE FEET OF POTCHEFSTROOM SOILS

On account of the solubility of nitrates, and the fact that our hot season and rainy season coincide, thus giving conditions for optimum nitrification, it was deemed necessary to take a number of depth samples, to throw some extra light on the observations obtained only from the surface 12 inches.

By the time the first of these samples was taken the middle of the rainy season was upon us, but the evidence is such as to indicate that by January 25 the nitrates had barely passed the third foot.

The samples were taken by digging a pit large enough to enable the operator to handle a pick and reach a depth of 5 feet. One side was kept vertical and clean, and on this face the successive foot-samples were taken.

The results from no. 1 and 2 do not show very high amounts of nitric nitrogen, although both were taken on different fallow strips on the cultivated and irrigated soil which has been studied twice previously.

The results seem to bear out the conclusion in study III concerning the depression of nitrification in irrigated and cultivated soil.

The seepage water collecting in the fourth foot level of no. 1 contained 1.8 parts per million of nitric nitrogen.

As to the amount of nitrogen in the first 4 feet of the fallow strip of the dry-land plots, no. 4 is in great contrast to no. 1 and 2, although the soil-moisture content is not so good on the non-irrigated fallow.

No. 5 and 6 show up worst of all; they are both virgin soils of two very different types, both growing natural veld grass. The low-lying black clay loam showed no nitric nitrogen at all, while the well drained dry-land virgin soil (no. 6) showed just a little in the first foot.

It seems from the seasonal variation study that only a little nitrate is formed under the natural grass, which uses up that little promptly. If no. 7, maize after cowpeas, is compared with the fallow strip no. 4 near by, it will be noted that the average foot content is very similar but that the distribution is very different. It must be remembered, though, that 2.4 inches of rain fell in the last week of January, and this is sufficient to explain the difference in nitrates, in the first foot particularly. It must be noted too that the soil moisture in no. 7 is much greater than in no. 4.

The data furthermore show the benefit of cowpeas over bare fallow as regards nitrification. The strip on which no. 4 was taken had been fallow for 2 years, while no. 7 had grown a crop of cowpea hay, and was growing maize which was over 6 feet high at the time of the sampling, and still its average nitrate content for 5 feet was equal to that of the fallow.

Samples 8 and 9 give the best direct evidence of the effect of heavy rainfall driving the nitrates down into the lower depths, below the feeding zones of the crop roots. Between February 3 and 20 there had been considerable rainfall, including 5.6 inches in one week. Samples 8 and 9 are from the same plot but it will be noticed how much greater is the moisture content from the first to the fifth foot in the samples taken on February 20. Also the nitrates have decreased 75 per cent in the first foot as compared with the sample of February 3, while the nitrates in the third, fourth and fifth feet have increased considerably. In spite of the maize being 17 days older, the total nitrates have increased somewhat if the average content per foot is taken. If no. 8 and 9 are compared with no. 4 and 7 it will be seen that the average nitrate content per foot for 5 feet is better under bare fallow and under maize following cowpeas, than under maize after maize. At the time of sampling, too, the maize on no. 7 was much larger and more vigorous than that on no. 8 and 9. Both the actual yields of maize obtained, and the amounts of nitrates here recorded in table 15, point to the beneficial effects of cowpeas even when cut for hay, instead of being turned under. When

TABLE 15

*Amount of nitric nitrogen and soil moisture found at various depths, 1920*

| DEPTH OF SOIL | NO. 1 | | NO. 2 | | NO. 4 | | NO. 5 | | NO. 6 | | NO. 7 | | NO. 8 | | NO. 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January 20 | | January 21 | | January 23 | | January 23 | | January 26 | | January 30 | | February 3 | | February 20 | |
| | Near cage in experiment plots | | Near salt-bush in experiment plots | | Fallow strip dry-land plots | | Virgin soil, black clay loam, low-lying | | Virgin soil beside dry-land plots | | Maize after cowpeas, dry-land plots | | Maize after maize, dry-land plots | | Maize after maize, dry-land plots | |
| | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture | Nitric nitrogen | Soil moisture |
| *feet* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* | *p.p.m.* | *per cent* |
| 1 | 5.8 | 12.0 | 4.5 | 9.5 | 35.6 | 8.0 | Nil | 7.2 | 0.7 | 8.7 | 19.1 | 11.9 | 21.1 | 11.3 | 5.3 | 13.0 |
| 2 | 3.5 | 14.6 | Trace | 13.5 | 7.0 | 10.9 | Nil | 8.2 | Nil | 9.5 | 10.0 | 13.7 | 5.2 | 13.4 | 5.8 | 15.5 |
| 3 | 3.7 | 16.8 | Trace | 14.6 | 2.4 | 12.1 | | | Nil | 10.7 | 6.0 | 14.2 | 5.0 | 14.0 | 6.3 | 17.7 |
| 4 | Nil | 17.3 | Nil | 14.3 | 1.6 | 13.3 | | | | | 13.0 | 14.8 | 1.2 | 13.8 | 12.7 | 17.3 |
| 5 | | | | | | | | | | | Trace | 14.4 | Nil | 14.2 | 8.4 | 18.3 |
| Average nitrate content for 5 feet............. | 2.6 | | 0.9 | | 9.3 | | Nil | | 0.1 | | 9.6 | | 6.5 | | 7.7 | |

No. 3 consisted of water which collected overnight by underground seepage in the hole made for sample 1 (Cage). This water contained 1.8 parts per million of nitric nitrogen.

the sample was taken on February 20, the maize was 6 feet high and the ears were just beginning to form.

Some other two feet samples have already been discussed in the previous study. The results shown here with virgin soil together with those recorded in table 15, seem to indicate that nitrates are not found below the first 12 inches in a virgin soil in this locality.

The amounts found in the second foot of the cultivated soils, show that there was considerable nitrate there before the rainy season started, although not as much as was found in the surface 12 inches on the same date (fig. 1 and table 3).

TABLE 16

*Nitrates and soil moisture on various second-foot samples*

| LOCALITY | REMARKS | DATE OF SAMPLING | NITRIC NITROGEN | SOIL MOISTURE |
|---|---|---|---|---|
| | | | *p.p.m.* | *per cent* |
| Virgin soil | From the non-irrigated plots studied for seasonal variation | Oct. 3, 1919 | Nil | 9.8 |
| Teff | From the non-irrigated plots studied for seasonal variation | Oct. 3, 1919 | 1.8 | 10.9 |
| Cowpeas harvested | From the non-irrigated plots studied for seasonal variation | Oct. 3, 1919 | 5.1 | 12.8 |
| Cowpeas plowed under | From the non-irrigated plots studied for seasonal variation | Oct. 3, 1919 | 4.7 | 13.4 |
| Fallow | From the non-irrigated plots studied for seasonal variation | Oct. 3, 1919 | 6.8 | 13.6 |
| Virgin soil | From the non-irrigated plots studied for seasonal variation | Oct. 8, 1919 | Nil | 9.3 |
| Cultivated soil | From irrigated land used in study III | Oct. 8, 1919 | 1.8 | 8.2 |
| Virgin soil | From southeast of football field, same as used in study III | Oct. 8, 1919 | Nil | 6.6 |

If the amounts of nitrate found in these soils below the first foot are compared with those recorded by other workers, it can be seen that they are much superior to amounts recorded by Stewart in the Cache Valley, Utah, and also superior to the nitrate content of most of the depth samples taken at the Longerenong Agricultural College, Victoria, Australia, by Scott, Robertson and Richardson (36). Both these stations receive several inches less rainfall than Potchefstroom. The amounts of nitrate that Buckman found in 5-foot samples in Montana (5), however, are much higher than these recorded in this study by the writer. Buckman's figures were also obtained under a lower rainfall than that prevailing here.

On the other hand, the nitrates at different depths of the non-fertilized cultivated soil on this station are higher than those which the writer has seen recorded at the Rothamsted station.

*Summary of study VI*

1. A comparison of the nitric nitrogen in the first 5 feet of a non-irrigated cultivated soil with that in an irrigated cultivated soil, shows the non-irrigated soil of the same type to be much superior in nitrate content, although the irrigated soil does not get sufficient water to carry the nitrates to the fourth foot.

2. The virgin soil of this station shows very little nitrate in the surface 12 inches, and so far none has been recorded below this depth.

3. Land with a 6½-foot-high maize crop following cowpeas cut for hay, shows as good a nitrate content for 5 feet as the same land which has been bare-fallowed during that time.

4. Although the nitrates during a very active growing period of the maize between February 3 and 20 have decreased 75 per cent in the surface foot, yet to a 5-foot depth they have increased. The decrease in the surface foot is attributed chiefly to the heavy rainfall.

5. Land bare-fallowed and land on which maize followed cowpeas cut for hay, had a better nitrate content than the same land on which maize followed maize.

## VII. THE NITRIFYING POWER OF SOIL AT DIFFERENT DEPTHS

Apart from gathering some data concerning the amounts of nitrate found in the soil per foot in 5-foot sections, it was thought advisable to determine the actual nitrifying power of the soil at different depths.

For this purpose on April 12, 1920, a 5-foot hole was dug in the "maize after maize" section of the dry-land plots. One side of the hole was cut quite vertical and from this the successive foot-sections were cut and placed in sterilized glass screw-top jars. The spade was thoroughly washed and scrubbed and then immersed in strong lysol, after which it was again rinsed with clean tap-water, every time it was used. The surface and sides of each section were shaved with a clean spade, which was again cleansed as described above before the sample was taken. A sheet of zinc cleaned in the same way as the spade was used for catching each sample.

Each foot-sample was placed on clean brown paper and allowed to become thoroughly air-dried. One-hundred-gram portions were weighed off into small tins, and mixed with 0.07 gm. of dried blood, 0.03 gm. of ammonium sulfate, 0.17 gm. of bone meal, and 0.17 gm. of dried and finely ground cowpea hay. These amounts were sufficient to supply each 100 gm. of air-dry soil with 7.0 mgm. of nitrogen on which to test its nitrifying power.

The moisture content was made up to 70 per cent of the soil's water-holding capacity, and the tins were placed on a shelf of a store-room and lightly covered with brown paper on April 21. The writer had no incubator at his disposal, so the tins were left at room temperature for 6 weeks in a building not heated in any way. Meanwhile, the weather gradually became colder, as will be

seen from the temperature chart. This small room, however, has a very even temperature and for the first 2 weeks the thermometer remained in the vicinity of 65°F., but then it declined steadily, and during the last two weeks of the six, it ranged from 40° to 55°F. The temperature during the period of incubation was not sufficiently low to supress nitrification, but it undoubtedly retarded it. Table 17 records the nitrifying power of the soil at different depths.

TABLE 17

*Nitrifying power of soil at different depths*

| DEPTH OF SOIL | SOIL ALONE | | | SOIL AND DRIED BLOOD | | SOIL AND BONE MEAL | | SOIL AND AMMONIUM SULFATE | | SOIL AND COWPEA HAY | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrate at start | Nitrate after 6 weeks | Increase or decrease | Total nitric nitrogen | Increase or decrease from dried blood | Total nitric nitrogen | Increase or decrease from bone meal | Total nitric nitrogen | Increase or decrease from ammonium sulfate | Total nitric nitrogen | Increase or decrease from cowpea hay |
| *feet* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* |
| 1 | 8.5 | 15.9 | 7.4 | 13.2 | −2.7 | 22.5 | 6.6 | 17.2 | 1.3 | 20.5 | 4.6 |
| 2 | 19.3 | 19.8 | 0.3 | 24.2 | 4.4 | 22.0 | 2.2 | 23.4 | 3.6 | 22.6 | 2.8 |
| 3 | 9.3 | 11.4 | 2.1 | 9.4 | −2.0 | 9.5 | −1.9 | 10.0 | −1.4 | 11.7 | 0.3 |
| 4 | 1.2 | 1.5 | 0.3 | Nil | −1.5 | Nil | −1.5 | 0.9 | −0.6 | 0.6 | −0.9 |
| 5 | 1.1 | 0.6 | −0.5 | 0.5 | −0.1 | Nil | −0.6 | Nil | −0.6 | Nil | −0.6 |

The temperatures of the depth samples are included in the table 18 together with other data.

TABLE 18

*Data supplementary to table 17*

| SOIL TYPE AND REMARKS | DEPTH OF SOIL | LOSS ON IGNITION | NITROGEN | VEITCH LIME REQUIREMENT | HYGROSCOPIC MOISTURE | TEMPERATURE ON APRIL 12, 1920 |
|---|---|---|---|---|---|---|
| | *feet* | *per cent* | *per cent* | | *per cent* | °C. |
| Brown fine sandy loam containing an appreciable amount of clay; samples taken on dry-land plots, "maize after maize" section | 1 | 6.7 | 0.09 | Slightly alkaline | 1.9 | 21.2 |
| | 2 | 7.6 | 0.04 | Slightly alkaline | 1.9 | 21.0 |
| | 3 | 8.3 | 0.06 | Slightly alkaline | 2.4 | 20.8 |
| | 4 | 9.0 | 0.05 | Slightly alkaline | 2.6 | 20.0 |
| | 5 | 8.8 | 0.05 | Slightly alkaline | 3.4 | 20.0 |

This soil begins to get gravelly in the third foot, while the fourth and fifth feet consist of 80 per cent of concretionary limonite gravel not passing a 3-mm. sieve. The higher loss on ignition in the lower feet is probably due to the loss of water of hydration, the light yellow color of the soil indicating much less organic matter than in the first 2 feet. The amount of hydroscopic moisture also increases with successive depths.

In spite of unfavorable conditions there was considerable nitrification in the first foot, as will be seen from table 17, also some activity in the second foot,

a little in the third foot, but a loss in nitrates in every case in the fourth and fifth feet, where nitrogenous fertilizers have been added. Beckwith, Vass and Robinson (2) in Oregon also found that dried blood and ammonium sulfate sometimes depressed nitrification. The total amount of nitric nitrogen in the second foot is greater, but it was greater at the beginning, and has not increased as much during incubation as that in the first foot.

A number of other soils which will be recorded in the next study, were incubating under the same conditions as the above, and as some high amounts of nitrate were obtained in these the temperature could not have been very much against nitrification. The results in any case will show the relative nitrifying power of the different foot sections.

The third foot shows some little nitrification of the soil nitrogen, but a loss wherever dried blood, bone meal and ammonium sulfate have been added.

In general, bone meal has been best nitrified, followed in order by cowpea hay, ammonium sulfate, and dried blood.

Lipman (20) obtained nitrification in a number of samples from the fifth foot and even lower depths of California soil when incubated. Kelly (19) also shows strong nitrification by the fifth foot of a soil he studied in that region, while McBeth and Smith (33) with soils from the Greenville Experiment Farm, Utah, obtained much better results than the writer's, especially in the third, fourth and fifth feet. The bad, gravelly limonite subsoil (80 per cent gravel), may account in some way for the poor nitrification in the Potchefstroom third, fourth and fifth feet.

The writer intends to carry on this work with depth samples from other soil types in this vicinity.

*Summary*

1. In this particular soil type there appears to be hardly any nitrification below the second foot.

2. This seems further evidence that the large amount of nitric nitrogen, obtained in the fourth and fifth feet of several samples taken from this vicinity, and reported in the last study, was brought there from the first and second feet by rain-water.

3. The addition of nitrogenous fertilizers to the third, fourth and fifth-foot samples depressed nitrification.

4. There is a gradual decrease in the total nitrogen content of the soil from the first to the fourth foot.

5. The loss on ignition, on the other hand, shows an increase with depth which does not correspond to the decreasing amount of total nitrogen, as is usually the case, but does correspond with the increase in hygroscopic moisture.

It is likely there is considerable loss of water of hydration from the limonite, which would also account for the increase of loss on ignition of the successive feet.

## VIII. A NITRIFICATION STUDY ON WHALE MANURE

About 1500 tons of fertilizer are produced yearly in South Africa as a by-product of the whaling industry (32). After the blubber has been extracted the whale carcass is worked up into a fertilizer, in much the same way as meat meal from abattoirs. This product is sold under the name "whale guano."

A fertilizer manufacturer gave the writer three differently treated whale guanos: (a) ordinary whale guano, (b) ether-extracted whale guano and (c) sulfated whale guano.

An endeavor was made to ascertain whether the ether-extracted guano did not nitrify better than the ordinary whale guano, on account of being quite free of fat and oil. The ether extract amounted to 14.9 per cent of the original whale guano. The second point aimed at was whether the percentage of nitrification of the sulfated guano was not better than that of the ordinary, untreated substance. The sulfated guano contained 9.1 per cent of $P_2O_5$, of which 7.53 per cent was water-soluble.

A fine brown sandy loam, with a lime requirement of 1000 pounds per acre by the Veitch method, was used. One gram of each of the guanos was mixed with 100 gm. of air-dry soil, and distilled water was added to make up 70 per cent of the soil's water-holding capacity. The soils were incubated for 30 days at 28 to 30°C., and then the nitric nitrogen was determined.

The results obtained and the amounts of nitrogen in the soil and the guano are given separately in table 19.

TABLE 19

*Nitrification of whale guanos*

| SUBSTANCE USED | NITROGEN IN SOIL ALONE AND IN WHALE GUANO ALONE | TOTAL NITRATE PRODUCED | INCREASE OF NITRATE OVER SOIL ALONE | SOIL NITROGEN NITRIFIED AND GUANO NITROGEN NITRIFIED |
|---|---|---|---|---|
| | *per cent* | *p.p.m.* | *p.p.m.* | *per cent* |
| Soil alone | 0.069 | 75.6 | | 10.95 |
| Soil and ordinary whale guano | 7.972 | 139.8 | 64.2 | 8.05 |
| Soil and ether-extracted whale guano | 8.700 | 153.2 | 77.6 | 8.98 |
| Soil and sulfate whale guano | 3.187 | 122.9 | 47.3 | 14.84 |

According to this test, the nitrogen of the sulfated whale guano was the most efficiently nitrified, while the differences between the percentages of the ordinary whale guano and the ether-extracted falls well within the experimental error. The substances removed in the ether extract do not appear to retard nitrification. Taking equal weights of the sulfated and untreated whale guano, it can be seen that the sulfated contains 4.79 per cent less nitrogen, or 95.8 pounds less per ton of 2000 pounds. In this country nitrogen is worth about $1^s/1^d$ per pound, so the loss approximates $104^s$ per ton. In the writer's opinion this loss is not compensated by making 7.5 per cent of phos-

phoric oxide water-soluble or in making the remaining nitrogen more easily nitrifiable within a month.

In the study following this it will be seen that whale guanos were again used on two different soils of this district, in a comparative study of the nitrifiability of various nitrogeneous fertilizers. In the one soil, a reddish brown sandy loam of a heavier type than the one used in this study, and of about 600 pounds lime requirement, the sulfated guano is still ahead, but in the black clay loam containing 5.93 per cent of carbonate of lime, the sulfated guano produced the least nitrate of the three, whereas the ordinary whale guano in this soil gave quite the best results of the three, in fact was among the most efficiently nitrified of the nitrogenous fertilizers.

### *Summary*

1. In two out of three soils, both of which were slightly acid, the sulfated guano was best nitrified.
2. Although rendering water-soluble a small amount of phosphate and sometimes giving a better nitrifiable product, it is doubtful whether the sulfating process is advisable, in view of the fact that it causes a loss of nearly 5 per cent of total nitrogen.
3. The 14.9 per cent of material which can be extracted from ordinary whale gunao by ether does not appear to suppress nitrification, as was popularly supposed.

## IX. A COMPARATIVE STUDY OF THE NITRIFIABILITY OF TEN NITROGENOUS FERTILIZERS

The fertilizers used in this study were three differently treated whale guanos, calcium cyanamide, crayferine, which is the dried and ground by-product of the crayfish canning industry, dried blood, bone meal, ammonium sulfate, dried and finely ground cowpea hay and soil treated with sewage sludge.

The two most important soil types of this district were chosen for this test. The one soil is a reddish-brown loam, having a lime requirement of about 600 pounds per acre by the Veitch method. The sample was taken from the fallow strip of our dry-land fertilizer plots. This soil is representative of the chief dry-land type on which most of the maize and teff grass in this district are grown.

The other soil is a black clay loam containing 5.93 per cent of free carbonate of lime. It is of alluvial origin and is found chiefly for three to four hundred yards on both banks of the Mooi River and its tributaries. It is the chief soil type under irrigation in these parts, and is one of the richest soils both chemically and practically that the writer has met with in South Africa.

The field where this particular sample was taken has been under cultivation for 35 years. It has grown lucerne rye, oats, mangels and Sudan grass, and in dry seasons sometimes maize and teff grass.

According to Lipman and Burgess (23) the testing of nitrogenous fertilizers for availability is better done by nitrification than by ammonification trials, as many soils which produce ammonia readily do not produce much nitrate. According to many investigators, although crops do take up their nitrogen in various forms, it is taken up chiefly as nitrates. This is a further reason for making a nitrification instead of an ammonification test, to ascertain the relative value of these ten nitrogenous fertilizers on our two main soil types.

Apart from the above object, the writer wished to find out whether small quantities of the fertilizer, more in accordance with actual practice, were not better nitrified than large amounts in these soils. This knowledge would help in the ultimate decision of the amounts which should be used in such trials, a matter that is receiving considerable attention.

The writer also had in mind the opinions of Lohnis and Green (26), Allen and Bonazzi (1), and Kelly (19) on this same matter. All these workers show clearly the error in using large amounts of fertilizer for this test and point out that the value of the work of many investigators has been vitiated on this account.

Green, in his later work on nitrogen metabolism, used only enough ammonium sulfate to add 11.2 mgm. of nitrogen to each test flask (10).

The writer is particularly interested in the publications of the workers on semi-arid soils. Lipman and Burgess in one of their studies on California soils used 1 gm. of each fertilizer irrespective of the precentage of nitrogen it contained (21). Later Lipman, Burgess and Klein (24), in an incubation nitrification experiment on a great number of humid and arid soils, used 1 gm. each of cottonseed meal and dried blood and 0.2 gm. of ammonium sulfate. These supplied 47, 132 and 40 mgm. of nitrogen, respectively, to each 100 gm. of soil. It is noteworthy that the arid soils nitrified best the cottonseed meal and ammonium sulfate, both of which contained around 40 mgm. of nitrogen, while the blood meal containing three times that amount of nitrogen was not so well nitrified. The soils from humid areas, however, produced a higher percentage of nitrate from dried blood than the substances containing less nitrogen. Lipman and his co-workers state that they are well aware that 0.05 and 0.1 gm. of dried blood might have been better nitrified than 1 gm., but they believe that as the humid and arid soils were treated alike their results clearly give relative and comparative nitrification figures, although they may not be absolute values.

Kelly (19), also working on California soils, found that portions of dried blood containing 0.125 and 0.0625 gm. of nitrogen were quite as well nitrified as bone meal and ammonium sulfate containing approximately equal quantities of nitrogen. He points out that dried blood gives good results under field conditions in California when applied up to the rate of 1080 pounds per acre and is well nitrified. He concludes that Lipman's bad results with dried-blood nitrification trials on California soils is due to his using 18.5 times more than is applied in actual farm practice.

Sakett in Colorado (40) used 100 mgm. of nitrogen in the form of ammonium sulfate, ammonium carbonate and ammonium chloride. Fraps (8) in Texas used 50 mgm. of nitrogen in the form of sheep manure and ammonium sulfate to test the nitrifying power of the soils of that state.

The writer in this study used 1 gm. of each fertilizer irrespective of its nitrogen content and also just enough to add 7 mgm. of nitrogen to each 100 gm. of soil. This is a lower amount than was used by any of the workers herein referred to, except Brenchley and Richards (3) who used 6 mgm. of nitrogen as sewage sludge. When worked out on the acre basis 7 mgm. would give 175 pounds of nitrogen per acre, or 1750 pounds of a 10 per cent dried blood. This is more than ten times the amount usually applied under field conditions in South Africa, but it is doubtful whether smaller quantities of material could be used without introducing a very large experimental error.

The writer has chosen the incubation time and temperature as used by the majority of workers on semi-arid soils, viz., one month (30 days) at 28° to 30°C. At the beginning the soils had distilled water added up to 70 per cent of their water-holding capacity, and on two other occasions small quantities were added to make up for what was lost in the incubator. The results are given in table 20.

If the sewage soil and calcium cyanamide results are omitted, then the remainder show that in 62.5 per cent of the results, the smaller amount of nitrogen was more efficiently nitrified than the larger, under the conditions of the experiment. One gram of ammonium sulfate was fairly well nitrified in the black clay loam containing plenty of lime, but in the other slightly acid soil, nitrification was depressed very much.

With the two exceptions already named, both soils nitrified the other fertilizers quite well, although the black clay loam produced considerably better results than the other. Crayferine, ammonium sulfate, ordinary whale guano, and cowpea hay were best nitrified.

The soil treated with sewage sludge, strange to say, gave very unexpected results, and probably the sample sent here contained some substance deleterious to nitrification.

Both Lipman and Burgess (22) and Brenchley and Richards (3) report very favourable nitrification results with sewage sludge, in California and in England.

The writer was sent a sample supposed to be sewage sludge, but on analysis it had only 0.33 per cent of nitrogen, and on inquiry was found to be soil treated with sewage sludge and not the sludge itself. The original sample contained, in addition to the above nitrogen, 465.4 parts per million of nitric nitrogen.

Calcium cyanamide, in both small and large amounts, depressed nitrification below that of the soil control. Some field trials give results which make this substance compare favorably with sodium nitrate and ammonium sul-

TABLE 20

*Comparative nitrification of ten fertilizers*

| SOIL AND FERTILIZERS | SOIL 53, BLACK CLAY LOAM | | | | SOIL 54, BROWN SANDY LOAM | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen added by fertilizer | Total nitrate found | Increase over soil nitrate alone | Nitrogen nitrified | Nitrogen added by fertilizer | Total nitrate found | Increase over soil nitrate alone | Nitrogen nitrified |
| | *mgm.* | *p.p.m.* | *p.p.m.* | *per cent* | *mgm.* | *p.p.m.* | *p.p.m.* | *per cent* |
| Soil alone | 157.0 | 64.6 | | 2.0 | 100.0 | 71.8 | | 5.14 |
| Soil and ordinary whale guano | 79.72 | 414.4 | 349.8 | 43.9 | 79.72 | 208.6 | 136.8 | 17.1 |
| Soil and ordinary whale guano | 7.0 | 136.0 | 71.4 | 102.0 | 7.0 | 48.5 | Loss | Nil |
| Soil and ether-extracted whale guano | 87.0 | 438.8 | 374.2 | 43.0 | 87.0 | 325.6 | 153.8 | 17.6 |
| Soil and ether-extracted whale guano | 7.0 | 76.5 | 11.9 | 17.0 | 7.0 | 80.9 | 9.1 | 13.0 |
| Soil and sulfated whale guano | 31.87 | 170.4 | 105.8 | 33.1 | 31.87 | 139.0 | 67.2 | 21.1 |
| Soil and sulfated whale guano | 7.0 | 65.7 | 1.1 | 1.6 | 7.0 | 93.7 | 21.9 | 31.2 |
| Soil and calcium cyanamide | 180.0 | 4.3 | Loss | Nil | 180.0 | 1.3 | Loss | Nil |
| Soil and calcium cyanamide | 7.0 | 19.0 | Loss | Nil | 7.0 | 32.9 | Loss | Nil |
| Soil and crayferine | 60.8 | 274.0 | 209.4 | 34.4 | 60.8 | 307.3 | 235.5 | 38.7 |
| Soil and crayferine | 7.0 | 139.8 | 75.2 | 107.4 | 7.0 | 128.1 | 56.3 | 80.4 |
| Soil and dried blood | 105.0 | 666.4 | 601.8 | 57.3 | 105.0 | 84.6 | 12.8 | 1.2 |
| Soil and dried blood | 7.0 | 109.7 | 45.1 | 64.2 | 7.0 | 79.4 | 7.6 | 10.8 |
| Soil and bone meal | 40.0 | 240.5 | 175.9 | 43.9 | 40.0 | 264.1 | 192.3 | 48.1 |
| Soil and bone meal | 7.0 | 97.6 | 33.0 | 47.1 | 7.0 | 42.4 | Loss | Nil |
| Soil and ammonium sulfate | 205.0 | 771.1 | 706.5 | 34.4 | 205.0 | 1.6 | Loss | Nil |
| Soil and ammonium sulfate | 7.0 | 122.6 | 58.0 | 82.8 | 7.0 | 114.5 | 42.7 | 61.0 |
| Soil and ammonium sulfate | 41.0 | 503.6 | 439.0 | 107.0 | 41.0 | 151.6 | 79.8 | 19.4 |
| Soil and cowpea hay (dried) | 40.1 | 230.2 | 165.6 | 41.3 | 40.1 | 189.8 | 118.0 | 29.4 |
| Soil and cowpea hay (dried) | 7.0 | 105.3 | 40.7 | 58.1 | 7.0 | 92.0 | 20.2 | 28.9 |
| Soil and sewage soil | 3.3 | 54.5 | Loss | Nil | 3.3 | 30.7 | Loss | Nil |
| Soil and sewage soil | 1.9 | 39.6 | Loss | Nil | 1.9 | 56.9 | Loss | Nil |

Soil 53 contained 33.0 parts per million of nitric nitrogen before incubation.
Soil 54 contained 20.4 parts per million of nitric nitrogen before incubation.

fate; others show it to be harmful. The writer's results are quite in accord with those of Lipman and Burgess (21) with calcium cyanamide on semi-arid soils. These American workers point out that the European investigators, Grazia, Muntz, and Nottin, noted that if much longer incubation periods were allowed, the nitrogen in this fertilizer was finally almost completely transformed into nitrate.

This substance is not readily obtainable on South African markets and it would seem wiser for farmers to leave this form of nitrogenous fertilizer alone until the time it takes to be nitrified in our soils has been more accurately determined, as planting too soon after applying this fertilizer almost always affects the germinating seed adversely.

### *Summary*

1. This nitrification study showed that all the fertilizers with two exceptions were well nitrified.

2. The crayferine was best nitrified in all cases, followed in order by ammonium sulfate, ordinary whale guano, cowpea hay, bone meal, dried blood, ether-extracted whale guano, and sulfated whale guano.

3. With the exception of the sulfated whale guano, the fertilizers were much better nitrified in the alkaline black clay loam than in the slightly acid brown sandy loam.

4. The soil nitrogen in the lighter soil, however, was much more efficiently nitrified than that of the heavier type.

5. In 62.5 per cent of the cases, the smaller amount of nitrogen was more efficiently nitrified than the larger.

6. These results would seem to be an additional argument in favor of using smaller quantities of material, more in accordance with field practice, for nitrification studies such as these.

## X. THE NITRIFYING POWERS OF VARIOUS SOUTH AFRICAN SOILS[2]

On three separate occasions, between April and September, the writer received batches of soils from many sections of the Union for this study. The first batch of 18 samples were taken by the chemists or officers in charge of our different experiment stations in each province.

These soils had finished their 6 weeks' incubation by June. The other two batches arrived in August and September, and were taken by farmers who had attended the June Short Course and who had, after hearing what care had to be exercised in taking and despatching the samples, volunteered to undertake the work. Apart from careful personal instruction in the manner of sampling, the writer sent detailed typewritten directions to each of the

[2] The writer wishes to thank his colleagues, and the farmers who so kindly took and forwarded these soil samples from all over the Union, and so made this investigation possible.

TABLE 21

*The nitrifying powers of various soils—nitric nitrogen*

| NUMBER | LOCALITY AND SOIL TYPE | SOIL ALONE | | | | SOIL AND DRIED BLOOD | | SOIL AND BONE MEAL | | SOIL AND AMMONIUM SULFATE | | SOIL AND DRIED COWPEA HAY | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | At start | At finish | Increase | Nitrogen nitrified | Total | Increase or decrease from dried blood | Total | Increase or decrease from bone meal | Total | Increase or decrease from $(NH_4)_2SO_4$ | Total | Increase or decrease from cowpea hay |
| | | *p.p.m.* | *p.p.m.* | *p.p.m.* | *per cent* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* | *p.p.m.* |
| 1 | Rustenburg virgin sandy loam | 0.8 | 0.9 | 0.1 | 0.02 | 0.6 | −0.3 | 0.9 | | 1.2 | 0.3 | 0.8 | −0.1 |
| 2 | Rustenburg cultivated sandy loam | 27.6 | 65.7 | 38.1 | 5.08 | 73.2 | 7.5 | 83.7 | 18.0 | 93.2 | 27.5 | 53.7 | −12.0 |
| 3 | Glen O. F. S. virgin clay loam | 34.5 | 51.3 | 16.8 | 1.57 | 43.9 | −7.4 | 37.2 | −14.1 | 45.6 | −5.7 | 31.5 | −19.8 |
| 4 | Glen O. F. S. cultivated clay loam | 0.7 | 11.6 | 10.9 | 1.29 | 31.5 | 19.9 | 26.0 | 14.4 | 21.5 | 9.9 | 17.2 | 5.6 |
| 5 | Glen O. F. S. virgin fine sandy loam | 0.7 | 10.1 | 9.4 | 2.68 | 4.8 | −5.3 | 9.5 | −0.6 | 8.7 | −1.4 | 6.1 | −4.0 |
| 6 | Glen O. F. S. cultivated fine sandy loam | 1.0 | 5.9 | 4.9 | 0.9 | 11.0 | 10.0 | 17.9 | 12.0 | 19.1 | 13.2 | 7.4 | 1.5 |
| 7 | Cedara virgin silt loam | 0.6 | 2.5 | 1.9 | 0.08 | 1.6 | −0.9 | 1.7 | −0.8 | 1.4 | −1.1 | 2.7 | 0.2 |
| 8 | Cedara cultivated silt loam | 7.4 | 31.2 | 23.8 | 0.95 | 48.7 | 17.5 | 56.0 | 24.8 | 40.4 | 9.2 | 56.0 | 24.8 |
| 9 | Winkle spruit virgin fine sand | 2.0 | 8.3 | 6.3 | 2.73 | 23.7 | 15.4 | 17.2 | 8.9 | 2.5 | −5.8 | 18.6 | 10.3 |
| 10 | Winkle spruit cultivated fine sand | 0.8 | 0.6 | −0.2 | Nil | 1.2 | 0.6 | 1.7 | 1.1 | 1.0 | 0.4 | 1.0 | 0.4 |
| 11 | Winkle spruit virgin fine sand | 1.7 | 2.2 | 0.5 | 0.1 | 0.9 | −1.3 | 0.7 | −1.5 | 1.4 | −0.8 | 1.6 | −0.6 |
| 12 | Winkle spruit cultivated fine sand | 1.1 | 1.5 | 0.4 | 0.12 | 0.6 | −0.9 | 0.6 | −0.9 | 0.6 | −0.9 | 0.7 | −0.8 |
| 13 | Elsenburg virgin loam | 0.9 | 3.5 | 2.6 | 0.4 | 6.2 | 2.7 | 8.5 | 5.0 | 1.1 | −2.4 | 4.6 | 1.1 |
| 14 | Elsenburg cultivated loam | 2.2 | 1.3 | −0.9 | Nil | 5.0 | 3.7 | 4.5 | 3.2 | 0.8 | −0.5 | 2.6 | 1.3 |
| 15 | Middelburg virgin loam | 1.0 | 8.0 | 7.0 | 0.68 | 28.9 | 20.9 | 32.5 | 24.5 | 30.2 | 22.2 | 19.7 | 11.7 |
| 16 | Middelburg cultivated loam | 0.9 | 12.7 | 11.8 | 1.3 | 85.0 | 72.3 | 72.3 | 59.6 | 75.9 | 63.2 | 31.5 | 18.8 |
| 17 | Middelburg virgin loam | 1.0 | 11.0 | 10.0 | 0.95 | 48.0 | 37.0 | 33.8 | 22.8 | 34.5 | 23.5 | 17.3 | 6.3 |
| 18 | Middelburg cultivated loam | 5.4 | 30.9 | 25.5 | 2.34 | 117.9 | 87.0 | 43.5 | 12.6 | 87.7 | 56.8 | 58.0 | 27.1 |
| 19 | Klerksdorp virgin sandy loam | 2.9 | 40.4 | 37.5 | 4.31 | 74.5 | 34.1 | 94.6 | 45.2 | 89.5 | 49.1 | 70.6 | 30.2 |
| 20 | Klerksdorp cultivated sandy loam | 7.1 | 15.4 | 8.3 | 1.06 | 112.1 | 96.7 | 46.4 | 31.0 | 64.1 | 48.7 | 44.5 | 29.1 |
| 21 | Rustenburg virgin sandy loam | 0.8 | 12.0 | 11.2 | 2.6 | 3.2 | −8.8 | 12.9 | 0.9 | 9.8 | −2.2 | 18.0 | 6.0 |
| 22 | Rustenburg cultivated sandy loam | 0.8 | Trace | −0.8 | Nil | 4.7 | 4.7 | 24.6 | 24.6 | 3.2 | 3.2 | 7.7 | 7.7 |
| 23 | Kuruman virgin fine sandy loam | 0.8 | 25.1 | 24.3 | 2.53 | 73.1 | 48.0 | 30.0 | 4.9 | 58.2 | 33.1 | 45.9 | 20.8 |
| 24 | Kuruman cultivated fine sandy loam | 1.3 | 53.6 | 52.3 | 3.84 | 100.9 | 47.3 | 77.3 | 23.7 | 79.1 | 25.5 | 55.5 | 1.9 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | Standerton virgin clay loam | 1.0 | 10.0 | 9.0 | 0.44 | 5.0 | −5.0 | 14.6 | 4.6 | 4.7 | −5.3 | 8.5 | −1.5 |
| 26 | Standerton cultivated clay loam | 7.2 | 84.1 | 76.9 | 4.99 | 82.7 | −1.4 | 74.1 | −10.0 | 77.5 | −6.6 | 59.9 | −24.2 |
| 27 | Krugersdorp virgin sandy loam | 0.1 | 10.8 | 10.7 | 1.81 | 8.2 | −2.6 | 56.0 | 45.2 | 18.4 | 7.6 | 23.2 | 12.4 |
| 28 | Krugersdorp cultivated sandy loam | 2.5 | 21.2 | 18.7 | 3.46 | 69.1 | 47.9 | 54.2 | 33.0 | 39.3 | 18.1 | 45.6 | 24.4 |
| 29 | Pietersburg virgin coarse sand | 0.7 | 14.3 | 13.6 | 2.61 | 65.7 | 51.4 | 56.1 | 41.8 | 65.0 | 50.7 | 21.0 | 6.7 |
| 30 | Pietersburg cultivated coarse sand | 1.3 | 8.5 | 7.2 | 1.5 | 16.1 | 7.6 | 17.6 | 9.1 | 75.8 | 67.3 | 25.8 | 17.3 |
| 31 | Ventersdorp virgin dark chocolate loam | 0.6 | 7.2 | 6.6 | 0.8 | 44.0 | 36.8 | 67.7 | 60.5 | 45.2 | 38.0 | 24.8 | 17.6 |
| 32 | Ventersdorp cultivated dark chocolate loam | 3.7 | 21.9 | 18.2 | 2.84 | 60.2 | 38.3 | 24.4 | 2.5 | 21.9 | | 51.6 | 29.7 |
| 33 | Koekemoer virgin red sandy loam | 0.6 | 14.6 | 14.0 | 2.29 | 11.8 | −2.8 | 35.0 | 20.4 | 45.4 | 30.8 | 16.9 | 2.3 |
| 34 | Koekemoer cultivated red sandy loam | 4.8 | 17.5 | 12.7 | 2.64 | 66.2 | 48.7 | 24.4 | 6.9 | 17.6 | 0.1 | 26.9 | 9.4 |
| 35 | Lichtenburg virgin brown sandy loam | 0.7 | 2.5 | 1.8 | 2.14 | 33.5 | 31.0 | 35.5 | 33.0 | 43.2 | 40.7 | 23.7 | 21.2 |
| 36 | Lichtenburg cultivated brown sandy loam | 2.3 | 25.1 | 22.8 | 3.16 | 76.8 | 51.7 | 55.2 | 30.1 | 57.4 | 32.0 | 30.2 | 5.1 |
| 37 | Ladybrand virgin fine sandy loam | 0.6 | 2.0 | 1.4 | 0.25 | 17.3 | 15.3 | 17.6 | 15.6 | 7.7 | 5.7 | 3.4 | 1.4 |
| 38 | Ladybrand cultivated fine sandy loam | 4.3 | 26.3 | 22.0 | 3.18 | 81.5 | 55.2 | 64.9 | 38.6 | 37.1 | 10.8 | 73.5 | 47.2 |
| 39 | Kliptown virgin black clay loam | 2.8 | 175.2 | 172.4 | 2.25 | 200.2 | 25.0 | 196.0 | 20.8 | 282.2 | 107.0 | 36.1 | −139.1 |
| 40 | Rosetta Natal virgin light brown silt loam | 2.6 | 39.0 | 36.4 | 1.01 | 68.2 | 29.2 | 107.0 | 68.0 | 71.0 | 32.0 | 35.5 | −3.5 |
| 41 | Rosetta Natal cultivated light brown silt loam | 15.6 | 63.0 | 47.4 | 1.56 | 35.2 | −27.8 | 103.0 | 40.0 | 87.9 | 24.9 | 13.8 | −49.2 |
| 42 | Marquard virgin light brown fine sandy loam | 0.8 | 15.4 | 14.6 | 2.4 | 54.0 | 38.6 | 39.0 | 23.6 | 16.1 | 0.7 | 6.0 | −9.4 |
| 43 | Marquard cultivated light brown fine sandy loam | 6.3 | 21.7 | 15.4 | 2.65 | 61.4 | 39.7 | 27.6 | 5.9 | 62.6 | 40.9 | 23.7 | 2.0 |
| 44 | Butterworth virgin grey sandy loam | 1.0 | 22.9 | 21.9 | 2.38 | 47.1 | 24.2 | 70.3 | 47.4 | 45.4 | 22.5 | 50.0 | 27.1 |
| 45 | Butterworth cultivated grey sandy loam | 2.7 | 21.3 | 18.6 | 2.75 | 64.1 | 42.8 | 54.2 | 32.9 | 45.9 | 24.6 | 18.5 | −2.8 |
| 46 | Melmoth Zululand virgin brown loam | 0.8 | 5.7 | 4.9 | 0.3 | 5.1 | −0.6 | 10.6 | 4.9 | 3.6 | −2.1 | 4.1 | −1.6 |
| 47 | Melmoth Zululand cultivated brown loam | 5.3 | 75.3 | 70.0 | 0.4 | 119.5 | 44.2 | 106.8 | 31.5 | 66.2 | −9.1 | 53.0 | −22.3 |
| 48 | Mooi River Natal virgin light brown clayey loam | 0.9 | Trace | Loss | Nil | Trace | Loss | Trace | Loss | Trace | Loss | Trace | Loss |
| 49 | Mooi River Natal cultivated light brown clayey loam | 1.3 | 32.4 | 31.1 | 3.3 | 59.3 | 26.9 | 50.6 | 18.2 | 61.8 | 29.4 | 4.7 | −27.7 |
| 50 | Molteno virgin light brown sandy loam | 1.9 | 6.2 | 4.3 | 0.5 | 40.4 | 34.2 | 50.3 | 44.1 | 48.7 | 42.5 | 5.1 | −1.1 |
| 51 | Molteno cultivated dark brown clay loam | 14.6 | 70.7 | 56.1 | 4.0 | 60.7 | −10.0 | 97.2 | 26.5 | 115.1 | 44.4 | 97.5 | 26.8 |
| 52 | Potchefstroom virgin greyish black clay loam | 5.9 | 65.7 | 59.8 | 3.0 | 129.1 | 63.4 | 126.1 | 60.4 | 166.3 | 100.6 | 80.0 | 14.3 |
| 53 | Potchefstroom cultivated greyish black clay loam | 33.0 | 64.6 | 31.6 | 2.0 | 109.7 | 45.1 | 97.6 | 33.0 | 122.6 | 58.0 | 105.3 | 40.7 |
| 54 | Potchefstroom cultivated brown sandy loam | 20.4 | 71.8 | 51.4 | 5.14 | 79.4 | 7.6 | 42.4 | −29.4 | 114.5 | 42.7 | 92.0 | 20.2 |

volunteer farmers when he was ready for the soils. From the keen interest shown, there is every reason to believe that the samples were carefully taken.

The samples on arrival, were all spread out on clean brown paper and thoroughly air-dried before being passed through a 3-mm. sieve, and weighed out into 100-gm. portions.

Soils 1 to 18 were incubated at room temperature for 6 weeks, as described in study VII. Soils 19 to 39 were incubated for 30 days at 28 to 30°C., and when they were completed, no. 40 to 54, which arrived later, were treated in like manner. It is to be regretted that no incubator was available when no. 1 to 18 arrived, but it is hoped that the 2 weeks' longer time has largely counterbalanced the lower temperature. The figures are not quite comparable, although the amount of soil nitrogen nitrified in several soils of this first batch is as high as the best results obtained with the batches in the incubator at a higher temperature.

The time and temperature of the incubation period were specially chosen, and they were the same as were used by Lipman and his co-workers in their comparative study on the nitrifying powers of 150 arid and 45 humid soils.

The writer bore the fact in mind that in this manner he would be able to obtain data which would be directly comparable with those on other semi-arid soils, and also with the results on humid soils on another continent. In this manner, he would be able to obtain further evidence to show whether or not nitrification in South African soils is as intense as has been supposed and reported in the past.

Lipman, Burgess and Klein used 1 gm. of dried blood, containing 132 mgm. of nitrogen, 1 gm. of cottenseed meal, containing 47 mgm. of nitrogen, and 0.2 gm. of ammonium sulfate, giving 40 mgm. of nitrogen.

The writer used enough dried blood (10.5 per cent nitrogen), ammonium sulfate (20.5 per cent nitrogen), bone meal (4 per cent nitrogen), and dried and finely ground cowpea hay (4 per cent nitrogen), to give to each 100 gm. of air-dry soil 7 mgm. of nitrogen. The reason for this small amount has been fully discussed in the previous study, which also showed that the percentage of nitrification is apt to be higher on account of using a smaller quantity of the fertilizer. If, then, the California soils and those from humid regions prove superior, it will not be for want of suitable conditions for the South African soils.

The best basis for comparison, however, will be the nitrification of the soil nitrogen itself, as that, after all, is the most important substance. The nitrification of the fertilizers will be discussed, but for the ultimate comparison of nitrification in those soils with soils of other countries, the percentage of soil nitrogen nitrified, will be the criterion. The data obtained are all given in table 21. More detail concerning the soils will be found in table 24, and a summary of table 21 in per cent of nitrogen nitrified is given in table 22.

TABLE 22

*Soil and fertilizer nitrogen nitrified*

| INCREASE OF NITRIC NITROGEN | | SOIL NITROGEN ALONE | DRIED BLOOD ALONE | BONE MEAL ALONE | AMMONIUM SULFATE ALONE | DRIED COWPEA HAY ALONE |
|---|---|---|---|---|---|---|
| *p. p. m.* | *per cent* | *number of soils* | *number of soils* | *number of soils* | *number of soils* | *number of soils* |
| Below 0.7 | Below 1 | 15 | 1 | 0 | 3 | 2 |
| 0.7–7 | 1–10 | 39* | 6 | 10 | 4 | 12 |
| 7–14 | 10–20 | | 1 | 3 | 4 | 6 |
| 14–21 | 20–30 | | 5 | 5 | 1 | |
| 21–28 | 30–40 | | 3 | 6 | 7 | 5 |
| 28–35 | 40–50 | | 6 | 8 | 5 | 4 |
| 35–42 | 50–60 | | 5 | 3 | 4 | |
| 42–49 | 60–70 | | 5 | 3 | 5 | 1 |
| 49–56 | 70–80 | | 3 | 1 | 1 | 0 |
| 56–63 | 80–90 | | 1 | 3 | 2 | 0 |
| 63–70 | 90–100 | | 3 | 1 | 3 | 0 |
| Loss from all soils............. | | | 15 | 8 | 14 | 18 |
| Loss from virgin soils........... | | | 11 | 5 | 10 | 11 |
| Stationary................... | | | 0 | 1 | 1 | 0 |
| Total number of soils tested.. | | 54 | 54 | 54 | 54 | 54 |

* The soil nitrogen nitrified was not above 5.2 per cent in any instance. This is much below the results obtained by Lipman and his co-workers.

*Discussion of results*

The soil nitrogen has not been nearly as well nitrified as that of the added fertilizers. In no case is the amount higher than 5 per cent.

If the summary of the results on these 54 soils is compared with the data of Lipman and his colleagues (25) the South African soils show up badly, as far as their efficiency in converting the soil nitrogen into nitrate is concerned. These American workers found that of the 45 soils from humid areas, 68 per cent transformed 10 per cent and more of the soil's own nitrogen into nitrate, under the same conditions that the writer used. The 150 California soils on which they worked, representing arid and semi-arid parts, came from four soil areas. Forty-seven per cent of the soils of the Riverside area, and 34 per cent of the soils of the Pasadena area transformed 10 per cent and more of the soil's nitrogen into nitrate.

These figures all show the greatly superior nitrifying powers of the soils from humid and semi-arid areas of North America, when compared with South African soils. The soils of the humid area far outclass those of the arid regions of California, which, again, far surpass ours.

Sackett of Colorado (39), in comparing the nitrifying efficiency of 23 Colorado soils with 22 soils from outside that state, as far as they were able to nitrify ammonium sulfate, ammonium carbonate, and ammonium chloride, concludes that the Colorado soils are much superior.

Lipman and his co-workers, however, show that if Sackett's figures are compared with theirs on the basis of soil nitrogen nitrified, only 21 per cent are found that produced 70 parts per million and upwards of nitric nitrogen, whereas 45 per cent of the Pasadena soils did this. When the writer's figures are judged by the same standard, only 3.7 per cent qualify.

Compared with Frap's results on the percentage of soil nitrogen nitrified by Texas soils in 4 weeks, the South African soils are somewhat superior.

*Nitrification of the added fertilizers*

When table 22 is examined, it will be seen however, that the dried blood, bone meal and ammonium sulfate were well nitrified and gave much better results than the cowpea hay. The cowpea hay was added absolutely dry, a distinct disadvantage, as in the field it is turned under green and decomposes more easily in that condition. Whiting and Schoonover (49) have recently published a paper in which they show that cured clover tops do not decompose and nitrify as easily as green clover tops. When the other three ferilizers are compared with one another as regards the amount of nitrate nitrogen produced over 40 per cent then the dried blood and the ammonium sulfate give equal results and the bone meal is a close third. But when compared on a 50 per cent and upwards basis, then dried blood is first, ammonium sulfate second, and bone meal third.

These results are not in agreement with those of Lipman, Burgess and Klein, who found that dried blood was the worst nitrified of all the substances they used with arid soils. They do agree, however, with Kelly's work, in that small quantities of dried blood, more in accordance with field practice, were well nitrified by semi-arid soils.

The writer's results are compared with Lipman and his colleagues' work in one more respect, viz., in regard to the actual losses of nitrate recorded where fertilizers were added.

TABLE 23

*Soils producing less nitrate with fertilizer plus soil nitrogen than from soil nitrogen alone*

| SOIL | DRIED BLOOD | BONE MEAL | AMMONIUM SULFATE | COWPEA HAY |
|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* |
| Cultivated and virgin | 27.7 | 14.8 | 25.9 | 33.3 |
| Virgin alone | 20.3 | 9.2 | 18.5 | 20.3 |

Dried blood in small quantities has not shown such a high percentage of loss as it did in the four California soils, viz., 35, 43, 63 and 50 per cent. With ammonium sulfate, except in one instance, the percentage loss was higher with our soils. The losses from cowpea hay also were greater in number than those produced by cottonseed meal.

In the South African soils, the losses in most cases were after the addition of the fertilizers to virgin soils. When the nitrifying powers of the virgin

soils alone are considered, the order of merit of the fertilizers is somewhat different, bone meal being first, ammonium sulfate second, and dried blood third; cowpea hay keeps its fourth place. This seems to indicate that on a newly broken-up veld soil, when sufficient time has elapsed to make fertilizing advisable, bone meal may be the best substance to apply if a nitrogen fertilizer is required.

In most instances, the cultivated soil was best nitrified. In several, where the cultivated soil was well nitrified, the virgin soil of the same type was practically at a standstill. Some soils, however, show better nitrification in the virgin than in the cultivated soil of the same type.

In table 24 will be found more detailed data concerning the 54 soils; the locality from which they came, the soil type, general remarks, the rainfall of the area, the loss on ignition, the nitrogen percentage of the soil, the hygroscopic moisture and the Veitch lime requirement.

The writer thought that he might be able to correlate some of these data with the efficiency with which nitrification took place in the soil. However, he has been unable to establish any relationship between the rainfall, the organic matter, the nitrogen content, and the hygroscopic moisture content of the soil, and its nitrifying power. Some of the soils that nitrified worst, came from the areas of highest rainfall, some of the best from the areas of lowest rainfall. Some soils with a low organic matter and nitrogen content gave a high percentage for the nitrification of soil nitrogen; some richer soils gave a very small percentage of nitrification. There seems to be more relationship between the nitrifying power and the lime requirement than between the latter and any of the other properties already mentioned. Even this relationship is not very striking, e.g., the nitrogen in soil 39, with a lime requirement of 14,400 pounds per acre, was well nitrified, and soil 54, with a lime requirement of 1124 pounds per acre, produced more nitrate nitrogen from its soil nitrogen than any other soil. The Winkle Spruit soils, no. 9, 10, 11 and 12, are both acid and alkaline, yet the most efficient nitrification was produced in one of the acid soils. Then again there are some soils that apparently follow the lime requirement as far as nitrification goes, i.e., good nitrification in alkaline soils and poor nitrification in those of a fairly high lime requirement.

A further study, made on the basis of the lime requirements, and in which lime is added, may give more interesting results. It seems, however, that very good nitrification goes on in soils which have quite a high lime requirement, according to the Veitch method.

## *Summary*

1. The nitrification of the soil nitrogen of the 45 humid soils, as recorded by Lipman and his co-workers, was much superior to the results which the writer of this paper obtained with 54 South African soils.

TABLE 24

*Some details of soils used in experiment X*

| NUMBER | LOCALITY AND SOIL TYPE | REMARKS | LOSS ON IGNITION | NITROGEN | HYGROSCOPIC WATER | VEITCH LIME REQUIREMENT (PER ACRE-FOOT) |
|---|---|---|---|---|---|---|
| | | | *per cent* | *per cent* | *per cent* | *pounds* |
| | *Rustenburg Experiment Farm.* | | | | | |
| 1 | Coarse yellowish brown sandy loam, virgin | Representative of large areas of the district; rainfall, 25.86 inches | 3.40 | 0.047 | 0.5 | A |
| 2 | Light yellowish brown coarse sandy loam, cultivated | | 3.27 | 0.075 | 0.9 | 580 |
| | *Glen Experiment Farm, O. F. S.* | | | | | |
| 3 | Greyish brown clayey loam, virgin, 10 yards from no. 4 | At edge of irrigated soil getting about 20 inches rainfall per annum | 4.75 | 0.107 | 3.5 | A |
| 4 | Greyish brown clayey loam, cultivated | Irrigated land, cultivated 4 years, crops good | 4.73 | 0.084 | 2.6 | A |
| | *Glen Experiment Farm, O. F. S.* | | | | | |
| 5 | Reddish brown fine sandy soil, virgin | Representative of the Glen dry lands; rainfall 18.3 inches | 2.05 | 0.035 | 1.0 | A |
| 6 | Light-reddish brown fine sandy loam, cultivated | Growing trees, Arizona, cultivated annually, dry lands | 2.42 | 0.054 | 1.4 | A |
| 7 | Same, virgin | Grass land | 14.10 | 0.225 | 3.6 | 8127 |
| | *Cedara Experiment Farm, Natal.* | | | | | |
| 8 | Brown silty loam | Cultivated 1 year, rainfall 33 inches | 14.53 | 0.249 | 3.6 | 6385 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *Winkle Spruit Experiment Farm.* | | | | | |
| 9 | Light brown fine sandy soil, virgin | Typical of Natal south coast soils | 1.1 | 0.023 | 0.1 | 174 |
| 10 | Same, cultivated | Rainfall 45 inches | 2.20 | 0.050 | 0.6 | 2322 |
| 11 | Brown fine sandy soil, virgin | From hillside | 1.48 | 0.049 | 0.3 | A |
| 12 | Light brown fine sandy loam | From hillside | 1.05 | 0.033 | 0.1 | A |
| | *Mulder's Vlei.* | | | | | |
| 13 | Coarse sandy greyish brown clay loam, virgin | Typical of wheat soils toward Malmesbury, rainfall 30.52 inches | 3.00 | 0.075 | 0.7 | 2300 |
| 14 | A coarse sandy greyish brown clay loam, cultivated | Cultivated for over 40 years, rainfall 30.52 inches | 2.65 | 0.064 | 0.7 | 3900 |
| | *Grootfontein Experiment Farm.* | | | | | |
| 15 | Middelburg Cape. Karroo red sandy loam, virgin | | 6.31 | 0.102 | 3.4 A | A |
| 16 | Same, cultivated | Typical of large areas in Karroo, rainfall 10 inches | 5.64 | 0.092 | 2.9 | A |
| 17 | Same, virgin | | 2.67 | 0.105 | 3.0 | A |
| 18 | Same, cultivated | | 5.89 | 0.109 | 2.8 | A |
| | *Klerksdorp.* | | | | | |
| 19 | Red sandy loam, virgin | Good average fertility and typical of large areas, subsoil grave land clay, rainfall 21.89 inches | 4.53 | 0.087 | 0.6 | 2730 |
| 20 | Dark red sandy soil, cultivated | | 4.30 | 0.078 | 0.7 | 1400 |

TABLE 24—*Continued*

| NUMBER | LOCALITY AND SOIL TYPE | REMARKS | LOSS ON IGNITION | NITROGEN | HYGRO-SCOPIC WATER | VEITCH LIME REQUIRE-MENT (PER ACRE-FOOT) |
|---|---|---|---|---|---|---|
| | | | *per cent* | *per cent* | *per cent* | *pounds* |
| | *Rustenburg.* | | | | | |
| 21 | Coarse reddish brown sandy loam, virgin | A little darker than the cultivated soil; near Wolhuters Kop, northern slopes, Magaliesburg; irrigated citrus land, soil 12 feet deep, rainfall 29.16 inches | 2.95 | 0.043 | 0.3 | 819 |
| 22 | Coarse red sandy loam, cultivated | | 2.55 | 0.029 | 0.2 | 1080 |
| | *Kuruman.* | | | | | |
| 23 | Grey fine sandy loam, virgin | Darker than cultivated soil below near Kamden Vryburg; calcareous subsoil 2 feet, irrigated land, for 8 years grew general crops, mangels and Sudan grass grow well, rainfall 19.69 inches | 5.60 | 0.096 | 1.0 | Contains 6.48 per cent $CaCO_3$ |
| 24 | Light grey fine sandy loam, cultivated | | 5.54 | 0.136 | 1.2 | 9.3 per cent $CaCO_3$ |
| | *Standerton.* | | | | | |
| 25 | Dark brown clay loam, virgin | From near Holmdene; a typical high veld soil, rich chemically but not easy to work, chief crops maize and teff, at 12 to 18 inches, the subsoil becomes darker and more clayey, rainfall 24.33 inches | 5.86 | 0.204 | 5.4 | 1620 |
| 26 | Same, cultivated | | 5.25 | 0.154 | 4.9 | 2160 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *Krugersdorp.* | | | | | |
| 27 | Brown medium fine sandy loam, virgin | Near Magaliesburg station; cultivated and irrigated citrus, rainfall 27.78 inches | 3.57 | 0.059 | 0.1 | 1530 |
| 28 | Reddish brown medium fine sandy loam, cultivated | | 3.01 | 0.054 | 0.2 | 700 |
| | *Pietersburg.* | | | | | |
| 29 | Coarse light brown sandy loam, virgin | Rainfall 21.69 inches, cultivated 5 years, maize, wheat and beans | 1.96 | 0.052 | 1.3 | A |
| 30 | Same, cultivated | | 2.09 | 0.048 | 1.2 | A |
| | *Ventersdorp.* | | | | | |
| 31 | Dark chocolate loam, virgin | This soil type occurs in circular depressions of about 100 yards diameter, overlying dolomite; manganese pebbles in subsoil, occurs north of Black Reef, rainfall 23.46 inches. | 4.95 | 0.083 | 0.6 | A |
| 32 | Same, cultivated | | 3.65 | 0.064 | 0.6 | 1220 |
| | *Koekemoer.* | | | | | |
| 33 | Red medium fine sandy loam, virgin | Virgin soil slightly darker, rainfall 23.59 inches, food fertility with good rain, easily blown and infested with ants | 3.17 | 0.061 | 0.6 | 740 |
| 34 | Same, cultivated | | 2.61 | 0.048 | 0.3 | 546 |
| | *Lichtenburg.* | | | | | |
| 35 | Chocolate fine sandy loam, virgin | Good fertile soil representative of best in district, chief crop maize; underlain by dolomite, rainfall 23.74 inches | 2.89 | 0.084 | 1.4 | 543 |
| 36 | Same, cultivated | | 2.71 | 0.072 | 1.4 | 1086 |

TABLE 24—*Concluded*

| NUMBER | LOCALITY AND SOIL TYPE | REMARKS | LOSS ON IGNITION | NITROGEN | HYGROSCOPIC WATER | VEITCH LIME REQUIREMENT (PER ACRE-FOOT) |
|---|---|---|---|---|---|---|
| | | | *per cent* | *per cent* | *per cent* | *pounds* |
| | *Ladybrand.* | | | | | |
| 37 | Light brown fine sandy loam, virgin | Derived from Cave sandstone; fine soil physically and also good chemically, rainfall 27.34 inches | 2.26 | 0.057 | 0.5 | 273 |
| 38 | Same, cultivated | | 2.36 | 0.069 | 0.7 | 546 |
| | *Near Johannesburg.* | | | | | |
| 39 | Kliptown black peaty loam, virgin | A very rich soil but has a large lime requirement, rainfall 28.4 inches | 21.13 | 0.764 | 5.7 | 14400 |
| | *Rosetta, Natal.* | | | | | |
| 40 | Light brown silt loam, virgin | Darker than cultivated, 8 inches deep, sour veld, rainfall 31.33 inches, yields good crop of potatoes with superphosphate and stable manure | 18.06 | 0.359 | 3.8 | 8625 |
| 41 | Same, cultivated for 5 years | | 11.83 | 0.303 | 6.3 | 8992 |
| | *Marquard O. F. S.* | | | | | |
| 42 | Light brown fine sandy loam, virgin | Of Cave sandstone origin; depth around 3 feet, then limonite and clay | 2.45 | 0.061 | 0.2 | 287 |
| 43 | Same, cultivated | Cultivated 35 years, darker in color than virgin, rainfall 22.95 inches | 2.35 | 0.058 | 0.1 | 575 |
| | *Blythswood Transkei.* | | | | | |
| 44 | Grey sandy loam, virgin | Soil about 2 feet, gravel and stony subsoil | 3.0 | 0.092 | 0.9 | 287 |
| 45 | Light grey sandy loam, cultivated | Cultivated 20 years, not renowned for fertility, rainfall 25.43 inches | 2.12 | 0.064 | 0.1 | 1150 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *Melmoth, Zululand.* | | | | | |
| 46 | Brown loam, virgin | Virgin soil darker than cultivated, 2 feet deep red subsoil; crop yields poor; rainfall 29.61 inches | 11.75 | 0.162 | 2.4 | 3162 |
| 47 | Same, cultivated | | 10.39 | 0.160 | 2.2 | 4600 |
| | *Escourt, Mooi River.* | | | | | |
| 48 | Light brown clay loam, virgin | Virgin soil darker than cultivated; both soils have a large amount of small round limonite pebbles; root crops and teff; cultivated about 6 years, soil 2 to 6 feet deep, rainfall 28.97 inches | 5.34 | 0.116 | 1.3 | 1725 |
| 49 | Same, cultivated | | 3.34 | 0.094 | 1.5 | 1100 |
| | *Molteno.* | | | | | |
| 50 | Light brown sandy loam, virgin | Soil 18 to 24 inches deep, underlain by subsoil of 10 feet, then sandstone; wheat and barley grown, rainfall 21.22 inches | 2.77 | 0.085 | 1.0 | 278 |
| 51 | Dark brown clay loam, cultivated | | 3.66 | 0 138 | 4.1 | A |
| | *Potchefstroom.* | | | | | |
| 52 | Dark greyish black clay loam, virgin | Very fertile soil, typical of irrigated soil in distribution | 9.93 | 0.200 | 4.0 | Contains 18.9 per cent $CaCO_3$ |
| 53 | Black clay loam, cultivated | | 5.14 | 0.157 | 3.2 | 5.93 per cent $CaCO_3$ |
| | *Potchefstroom.* | | | | | |
| 54 | Brown sandy loam, cultivated | Fallow strip of dry land plots studied for seasonal variation | 6.50 | 0.100 | 1.9 | 1124 |

2. Even the results from the majority of the soils of the semi-arid parts of California and Colorado are superior to the writer's figures, which are, again, better than the data from Texas soils.

3. It does not seem, from this study that nitrification in South African soils is as intense as has been hitherto supposed.

4. Dried blood, in small quantities, was the most efficiently nitrified of the four fertilizers used. Ammonium sulfate, bone meal and dried cowpea hay followed in order of merit.

5. With the virgin soils, bone meal was best nitrified, then ammonium sulfate, dried blood, and dried cowpea hay.

6. Nitrification in the cultivated soils was, in general, superior to that in the virgin soils.

7. No relationship could be established between the efficiency with which the soil nitrogen was transformed to nitrate, and the organic matter, the nitrogen, and hygroscopic moisture content of the soil, or the rainfall of the area from which the soil came.

8. There seems a perceptible relationship, in some cases at least, between the amount of nitrate produced from soil nitrogen, and the Veitch lime requirement of the soil.

## FINAL DISCUSSION AND CONCLUSIONS

The seasonal variation data seem to point to better and more active nitrification at Potchefstroom than at Rothamsted. In this the writer agrees with Watt but he cannot endorse that worker's opinion that nitrification in Transvaal soils is in general superior to that in the soils of most temperate climates. One reason is that seasonal-variation field data from Ithaca, N. Y., record very much superior amounts of nitric nitrogen than were found here.

Again, when 54 South African soils were incubated, most of them under the same conditions as used by Lipman and his co-workers, the resulting data were much inferior to those obtained by these investigators on 45 soils from humid areas of the United States. They also found, on using the actual percentage of soil nitrogen nitrified as the criterion, that these 45 soils from humid areas were superior to soils from the arid and semi-arid sections of California.

The writer had always believed that nitrification in South African soils was very active and had hoped to find it so. From the field and laboratory data obtained in these studies, however, the following conclusions seem reasonable:

### *Conclusions*

1. Nitrification in South African soils, when compared with that in soils from many other parts, cannot be said to be exceptionally active, although it is good compared with data from some areas.

2. These data add further evidence from another section of the globe, to that recently accumulated by workers in Western America, to show that nitrification is not so intense in the soils of arid and semi-arid regions, or always superior to that in the soils of humid areas.

3. However, nitrification seems quite adequate for the average crop production in this area of summer rainfall. The last study showed that 5 per cent of the soil's nitrogen on this farm could be nitrified under optimum conditions in 30 days. That means a capacity for producing about 180 pounds of nitric nitrogen per acre foot. This, though, is a higher capacity than was shown by most samples of the soils tested; nitric nitrogen was always found on the dry-land plots even at the time of the most active growth of the maize crop.

4. Where the maximum rainfall and temperature coincide, there is maximum nitrification at the time of greatest crop growth. Thus it seems that there is not much need of nitrogenous fertilizers in the summer rainfall area. On the other hand, farm practice shows great benefit from nitrogenous manures in the Cape areas of winter rainfall, where the optimum conditions of moisture and temperature occur at different times.

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